Libera split-solar angular distribution model (ADM) update: opportunities and challenges for the wide-field-of-view camera

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Laboratory for Atmospheric and Space Physics (LASP)

Thanks to Libera split solar ADM working group: Sebastian Schmidt, Mathew van den Heever*, Joshua Mauss*, Maria Hakuba, Dan Feldman, Peter Pilewskie, Bruce Kindel. *student

12 October 2022 | Earth Radiation Budget Workshop: Hamburg, Germany | Jake.J.Gristey@noaa.gov

Outline

- Background
  - ➢ Shortwave angular distribution model (ADM) basics
  - ➢ Libera split-shortwave ADM approach
- Camera-based ultraviolet-visible (VIS) ADMs
  - ➢ Angular sampling pattern
  - ➢ Spectral conversion
- Angular sampling camera simulation experiments
- Priorities for the future

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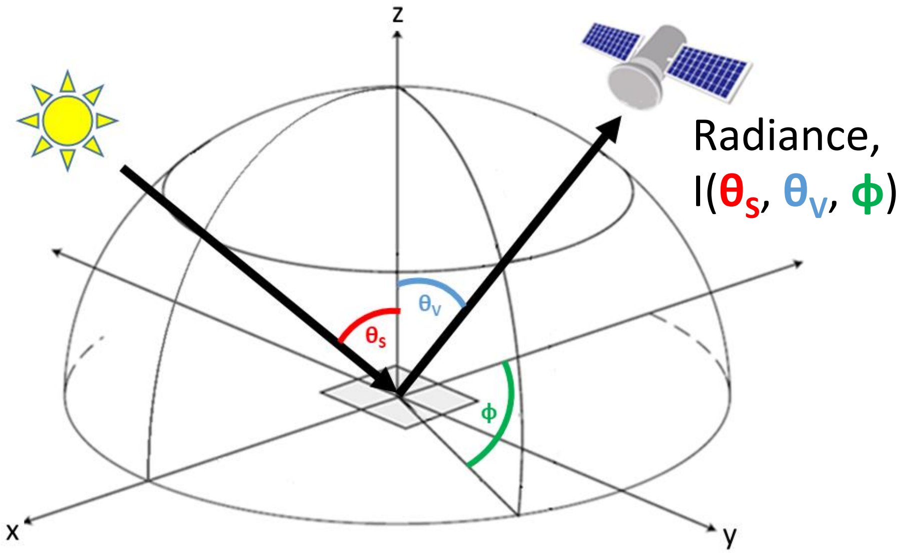
Shortwave ADMs: the basics

Solar-viewing geometry

- Solar zenith angle (θ_s)
- Viewing zenith angle (θ_v)
- Relative azimuth angle (ϕ)



Gristey et al., Remote Sensing [2021]

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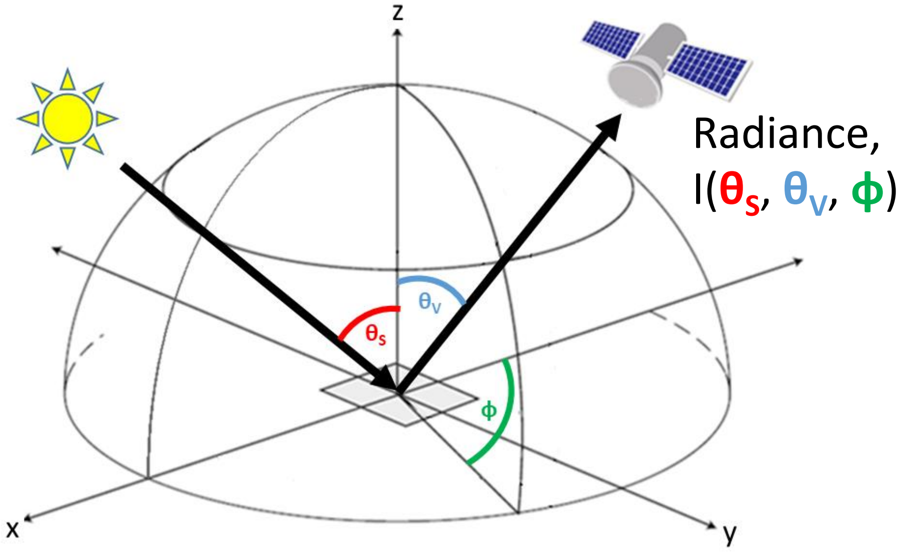

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Radiance, I(θ_s, θ_v, ϕ) →

Scene type →

Angular Distribution Model (ADM)

→ Irradiance, F(θ_s)

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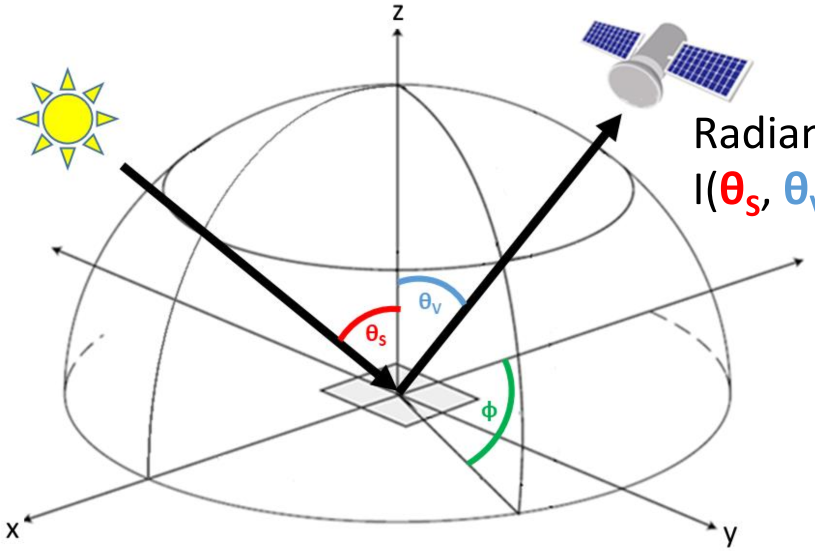
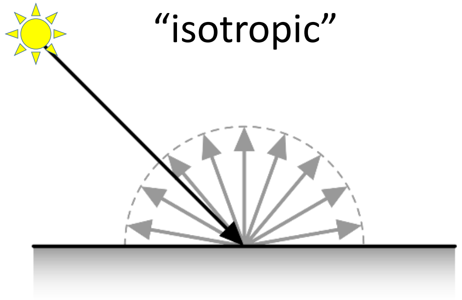


Radiance,
I(θ_s, θ_v, ϕ)

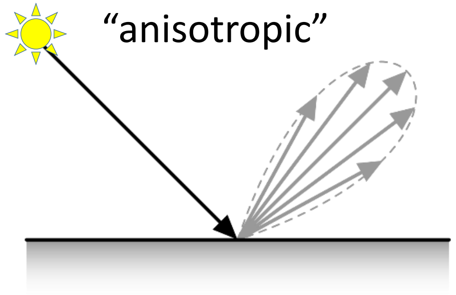
Gristey et al., Remote Sensing [2021]

Scene type

“isotropic”



“anisotropic”



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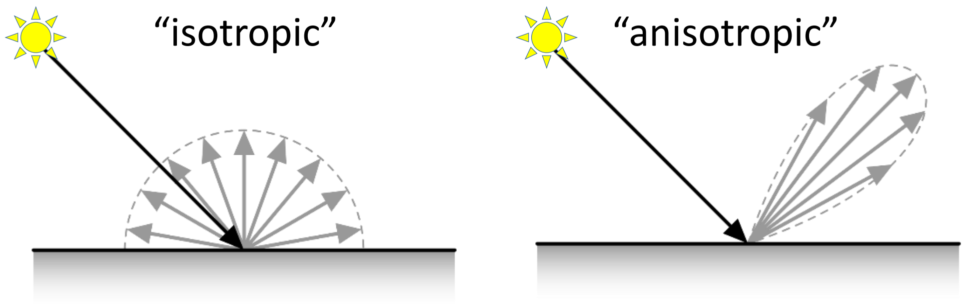

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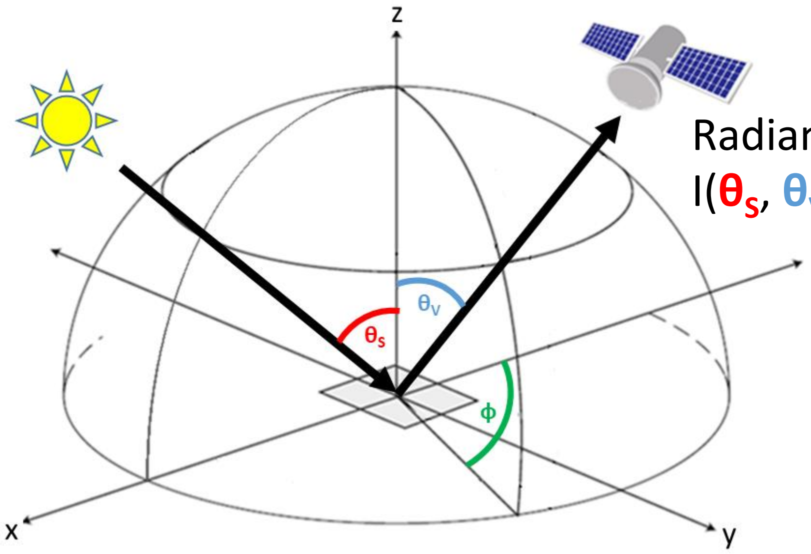

Radiance, I(θ_s, θ_v, ϕ)

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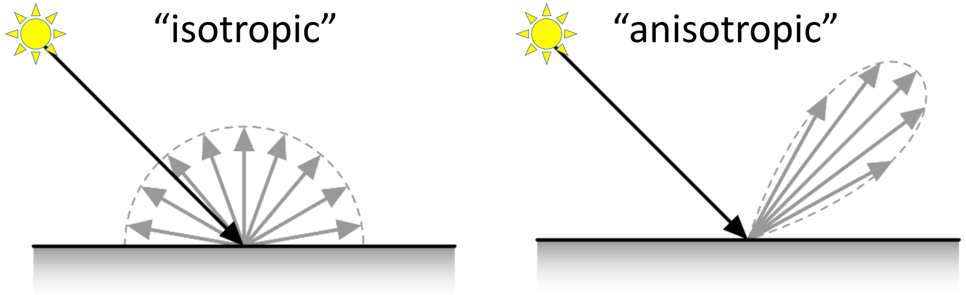
Radiance, I(θ_s, θ_v, ϕ) → Angular Distribution Model (ADM) → Irradiance, F(θ_s)

Scene type → Angular Distribution Model (ADM)

$$F(\theta_s) = \int_0^{2\pi}\int_0^{\pi/2} I(\theta_s, \theta_v, \phi)\cos\theta_v \sin\theta_v \, d\theta_v d\phi$$

Shortwave ADMs: the basics

Scene type

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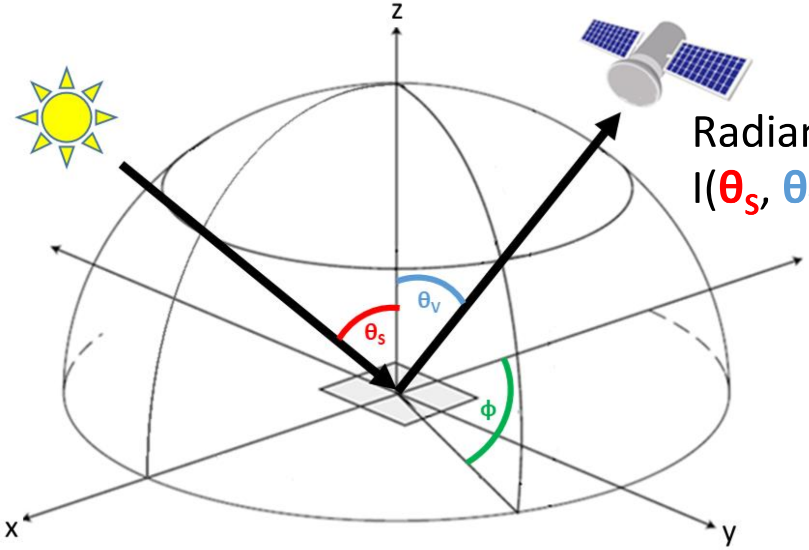

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isotropic: $= \pi I(\theta_s, \theta_v, \phi)$

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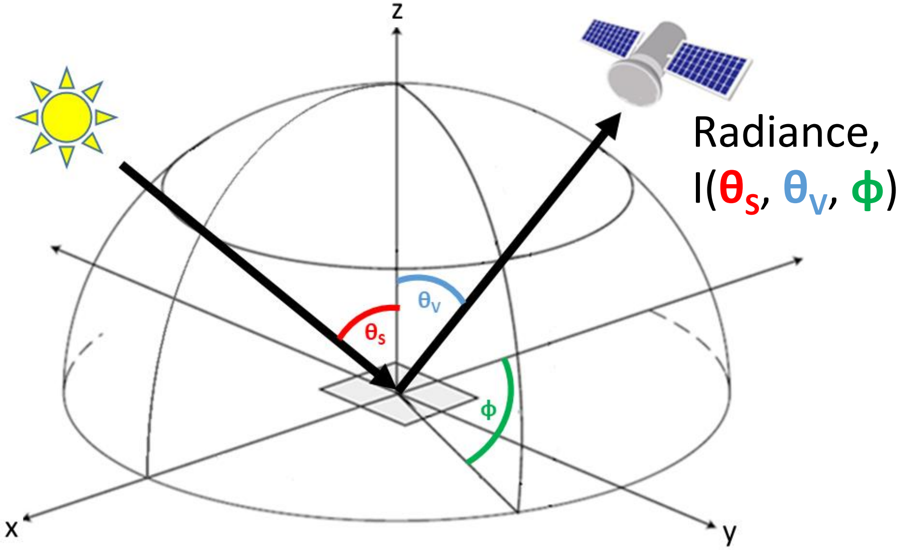

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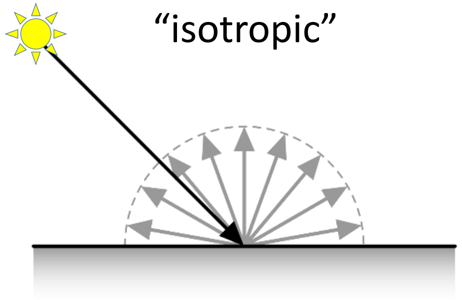

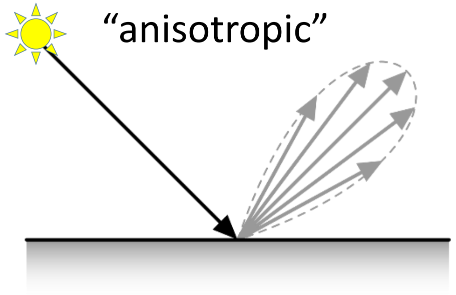

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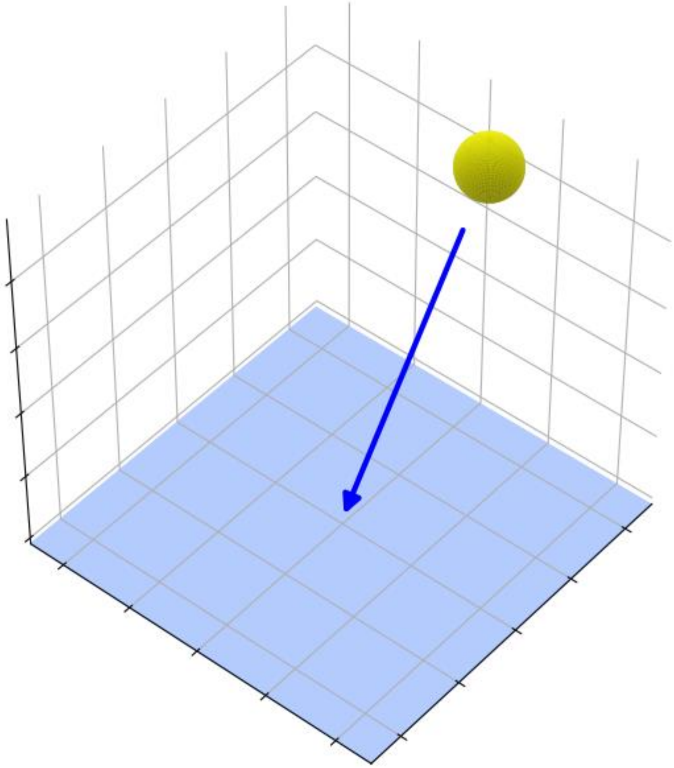
isotropic: $= \pi I(\theta_s, \theta_v, \phi)$

anisotropic: $= \dfrac{\pi I(\theta_s, \theta_v, \phi)}{R(\theta_s, \theta_v, \phi)}$

anisotropic factor

Generating anisotropic factors

Example: θ_S 30-40°, ocean, clear-sky, wind speed <3.5 m s^{-1}



From CERES TRMM ADMs: *Loeb et al., JAM [2003a,b]*

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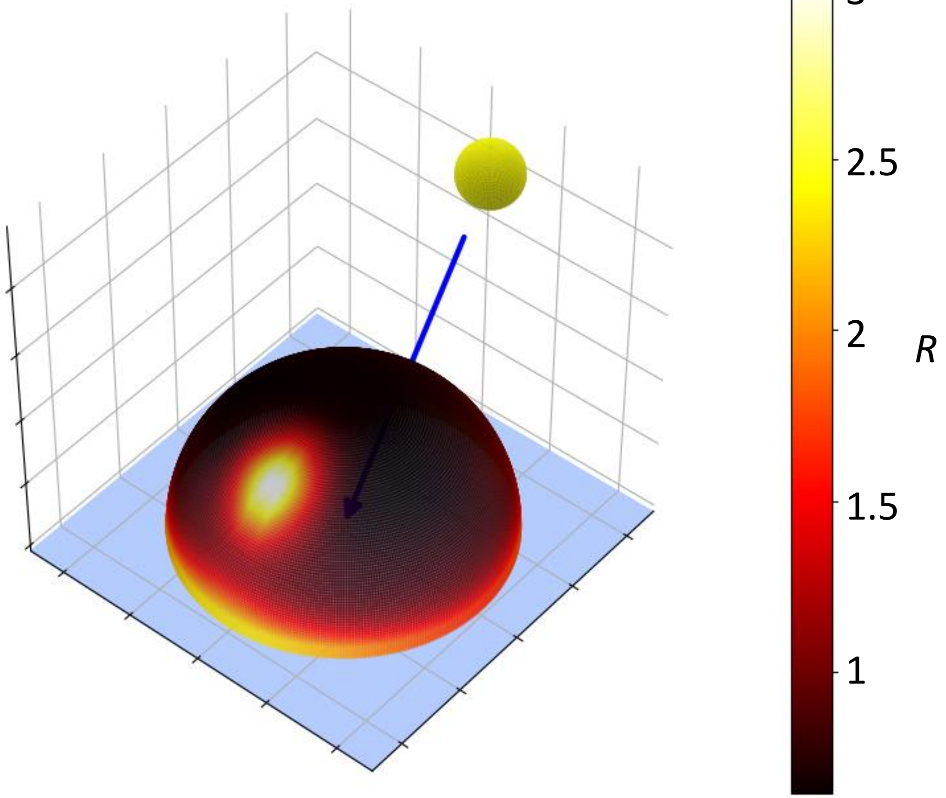

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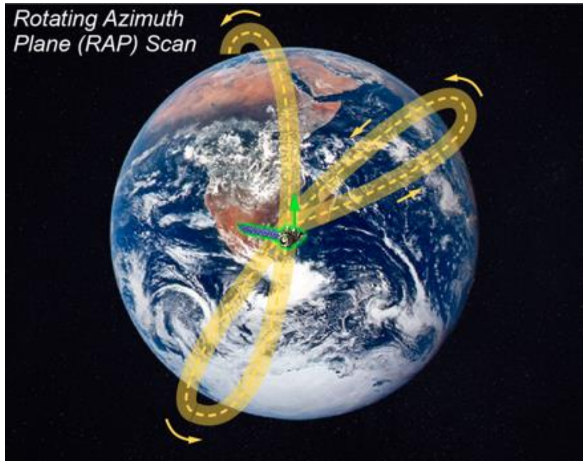

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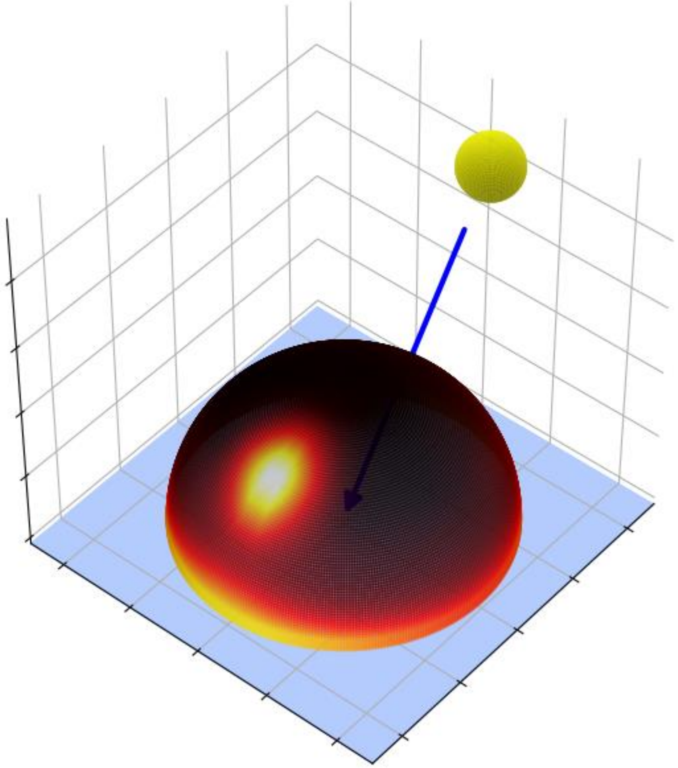
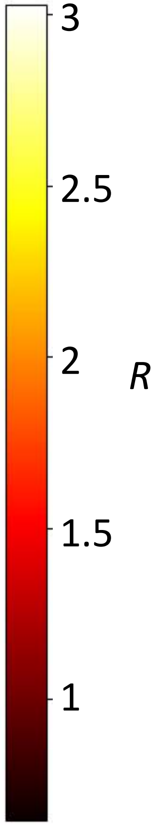
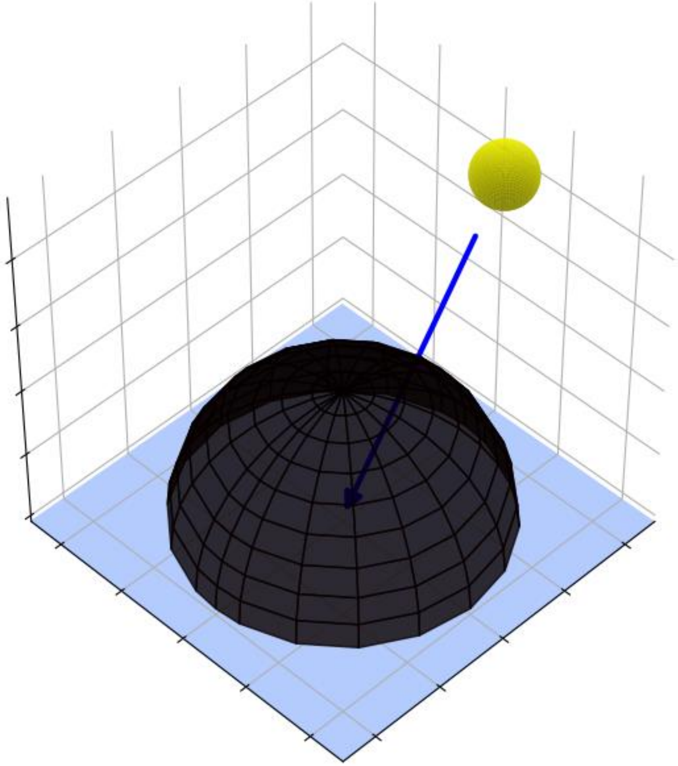




ADM generation



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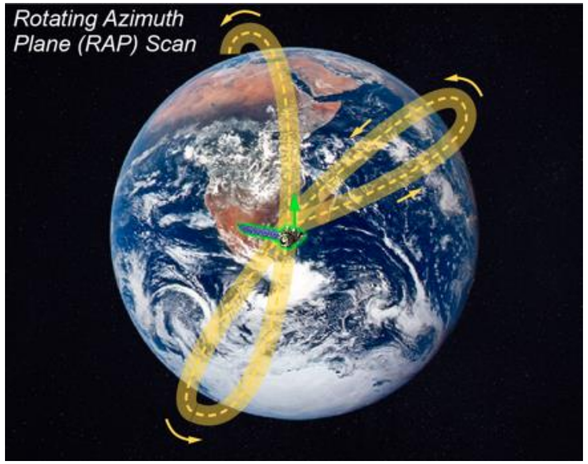

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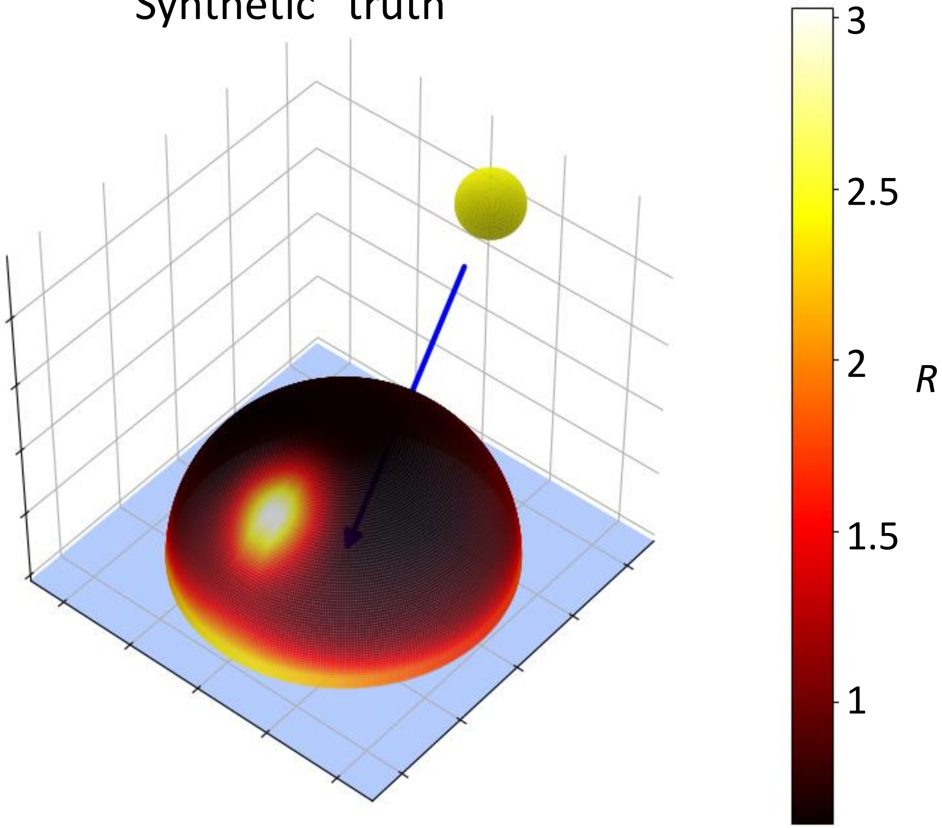

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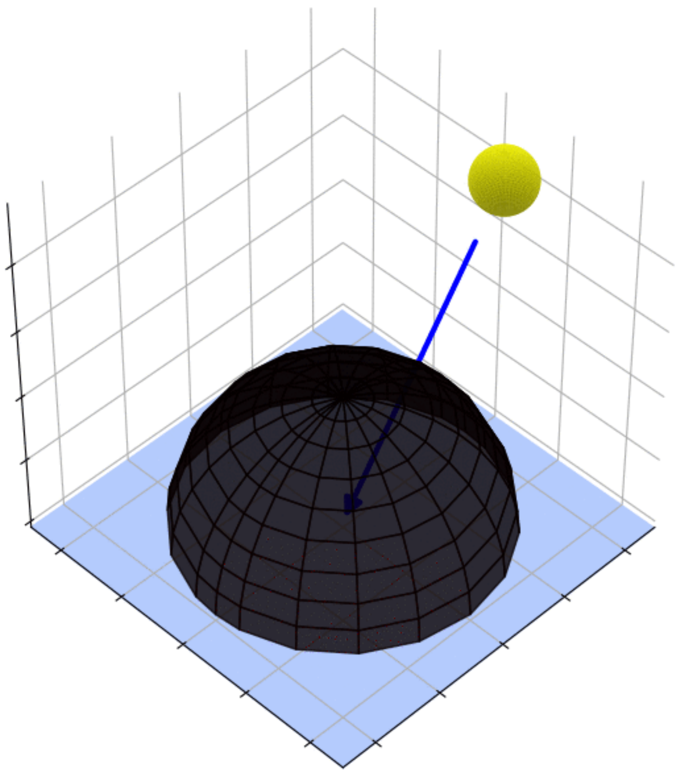

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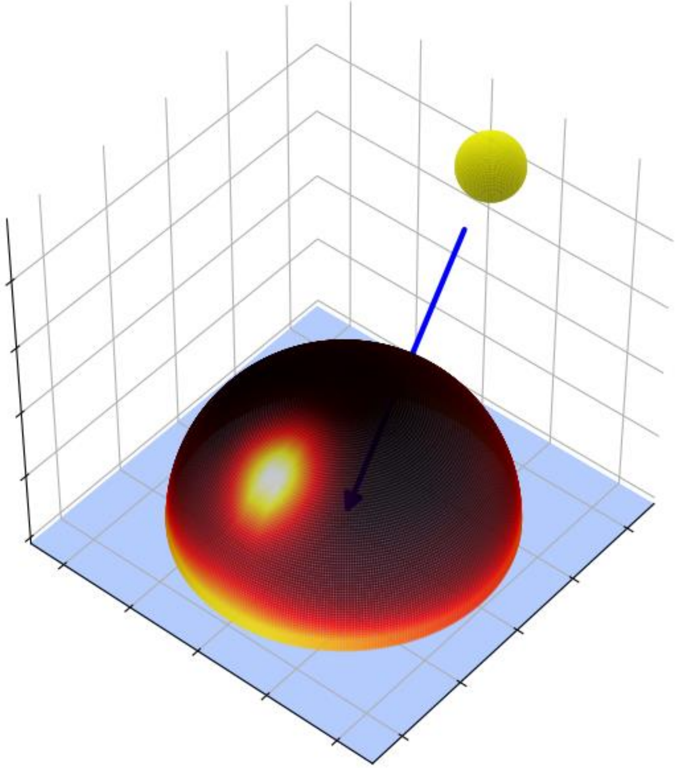

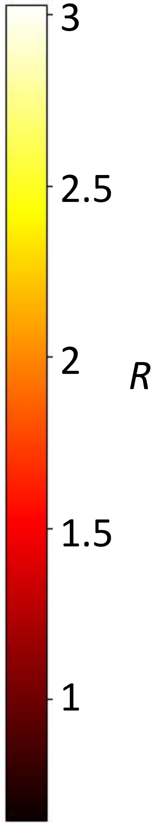

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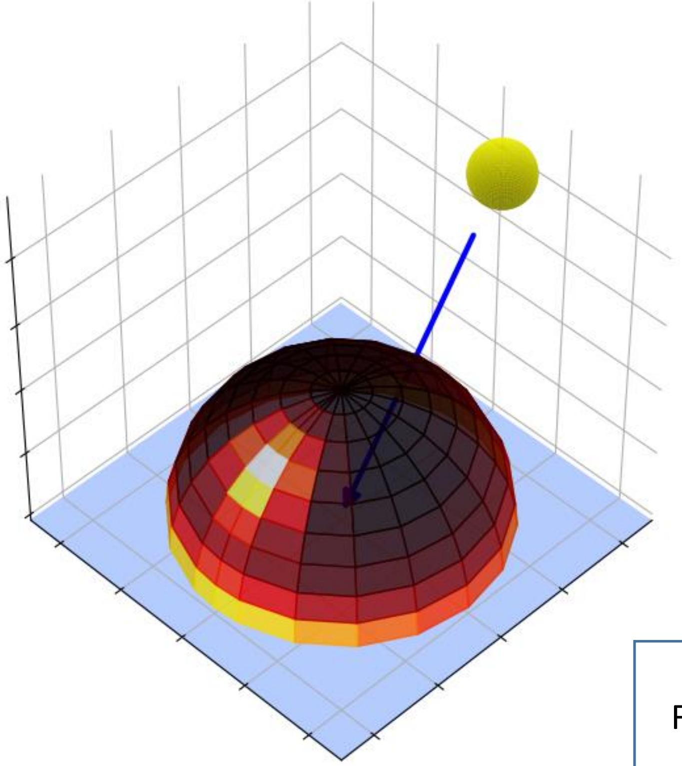

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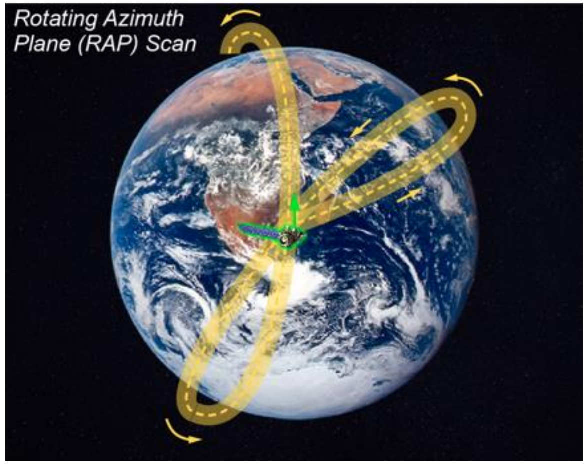

$$R(\cancel{\theta_S}, \theta_V, \phi) = \frac{\pi I(\cancel{\theta_S}, \theta_V, \phi)}{F(\cancel{\theta_S})}$$

For θ_V bin *i* and ϕ bin *j*:

$$R_{i,j} = \frac{\pi \overline{I_{i,j}}}{F}$$

$$F = \int_0^{2\pi} \int_0^{\pi/2} I(\theta_V, \phi) \cos\theta_V \sin\theta_V \, d\theta_V d\phi$$

$$\approx \sum_{i=1}^{N_i} w_i \sum_{j=1}^{N_j} w_j \overline{I_{i,j}} \quad \text{(or similar functional form)}$$

Libera split-shortwave ADM approach

- Split-SW ADMs do not exist; *how will Libera split-shortwave radiance be converted to irradiance?*

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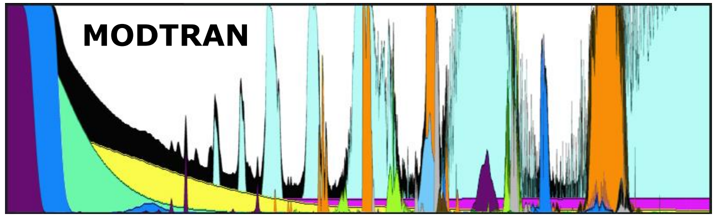

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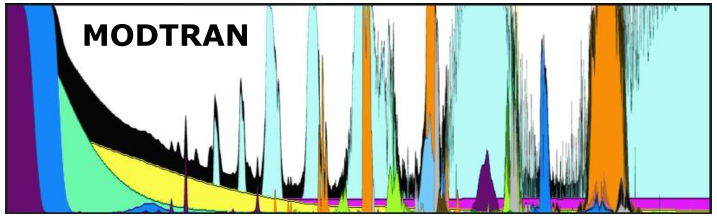
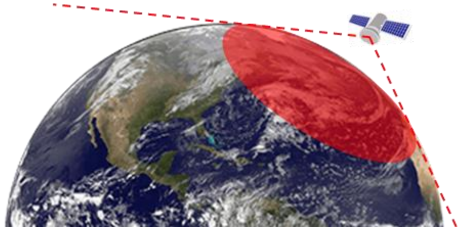


2. Wide-field-of-view camera ADMs *[shortly after launch]*



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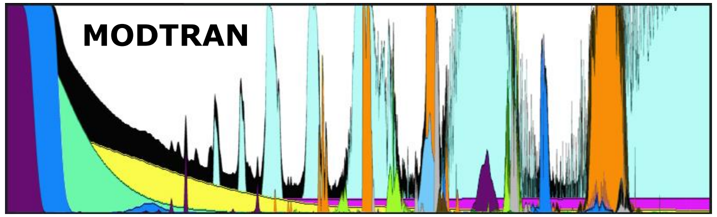

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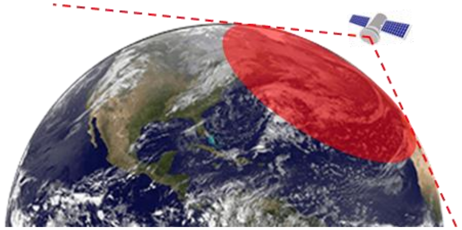
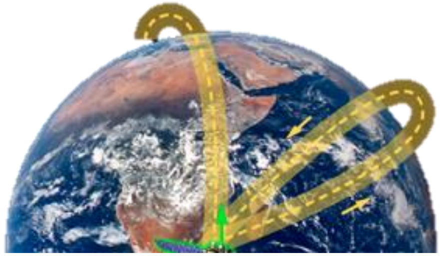


3. Primary split-SW radiometer RAPS ADMs *[later in mission]*



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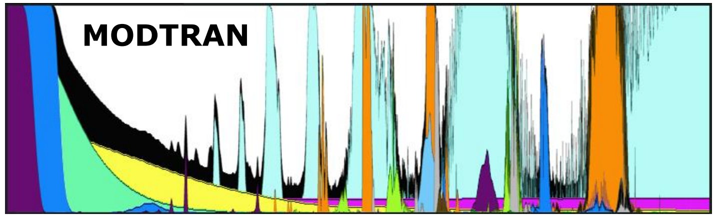

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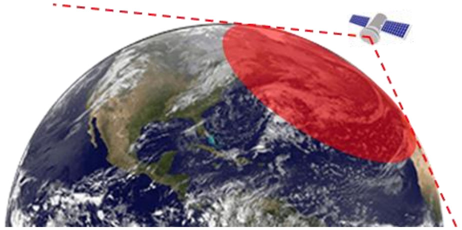

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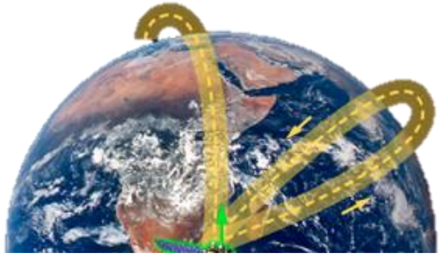

Imager independent / Libera only

Motivation: *“Advance the development of a self-contained, innovative & affordable observing system”.*

VIIRS / best available

Motivation: Provide the best possible split-SW irradiance estimates to the community using all of the available information.

Note: General approach is to develop new VIS ADMs and obtain NIR irradiance via subtraction

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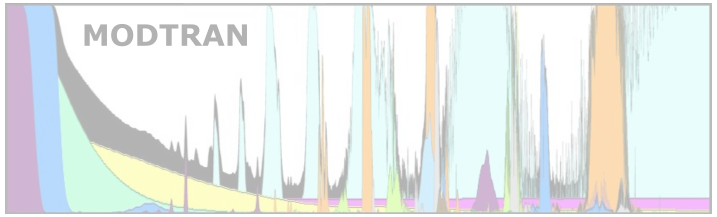

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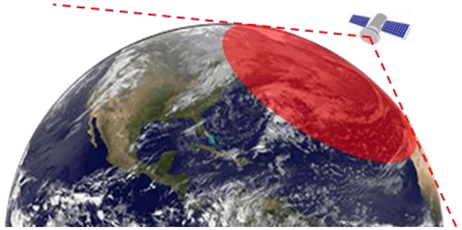

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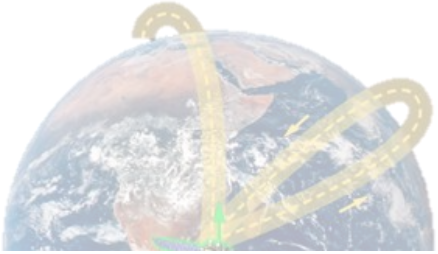

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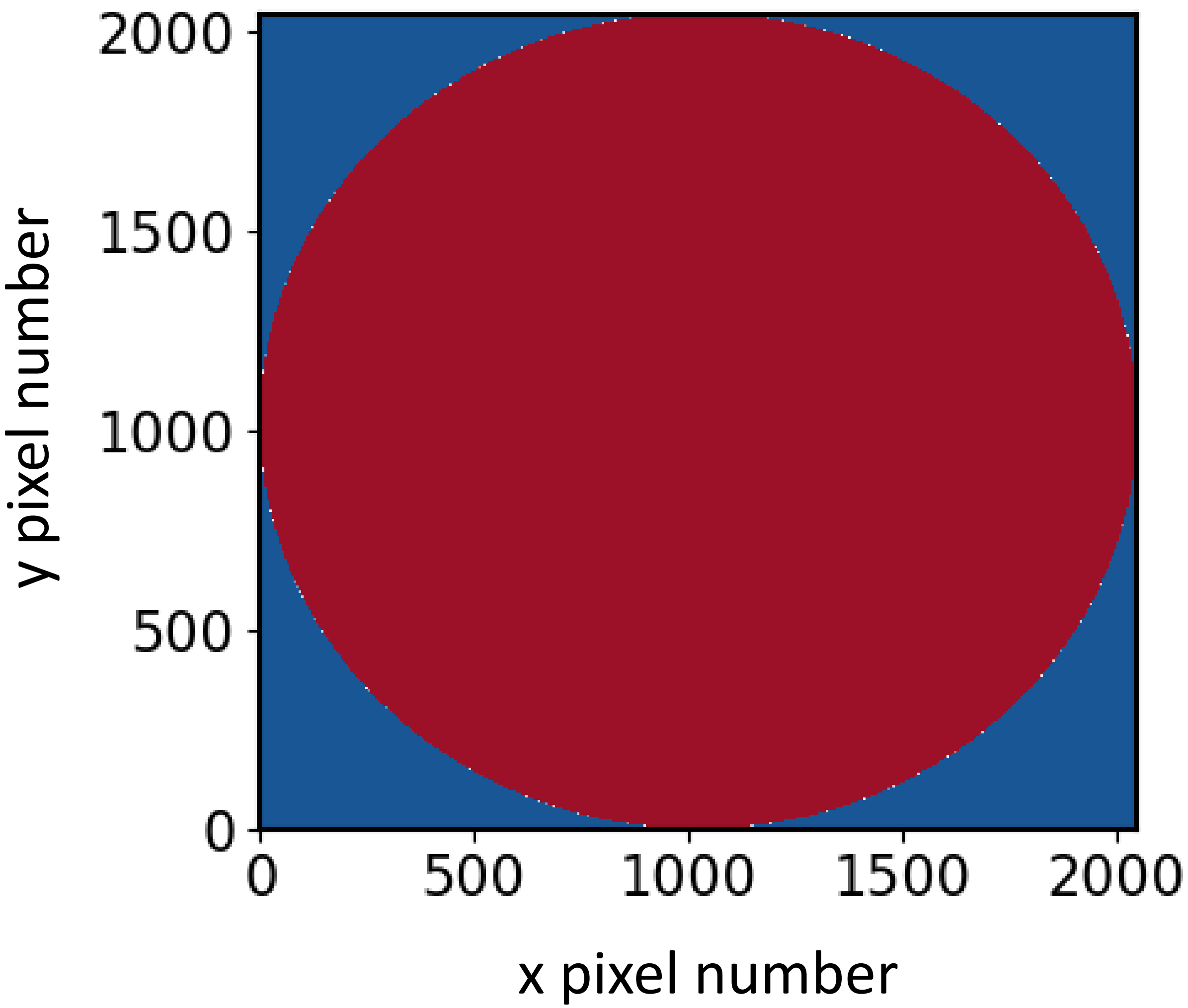
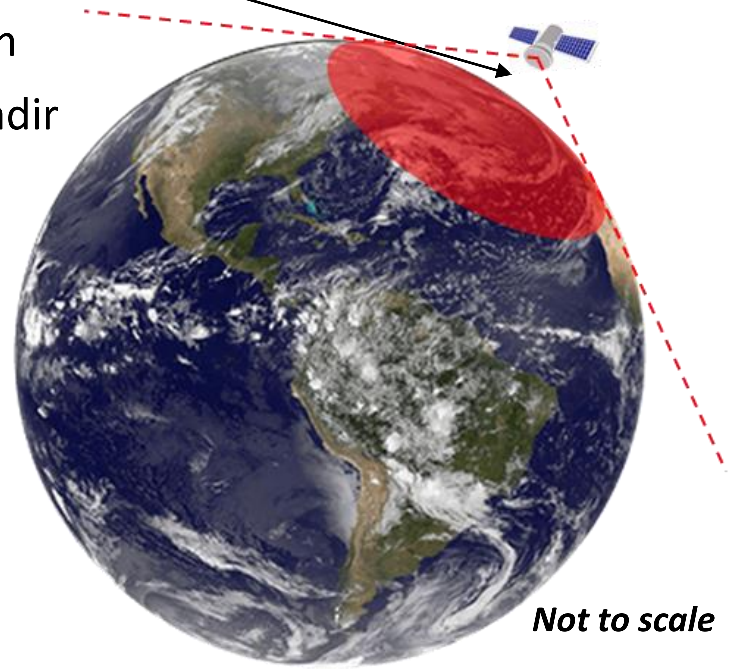
Libera camera characteristics



- 2048 × 2048 pixel array samples entire Earth disk
- horizon-to-horizon 124° field of view, (~6000 km @ surface)
- Single channel: 555 nm
- < 1km resolution @ nadir
- Exposure every 5 secs



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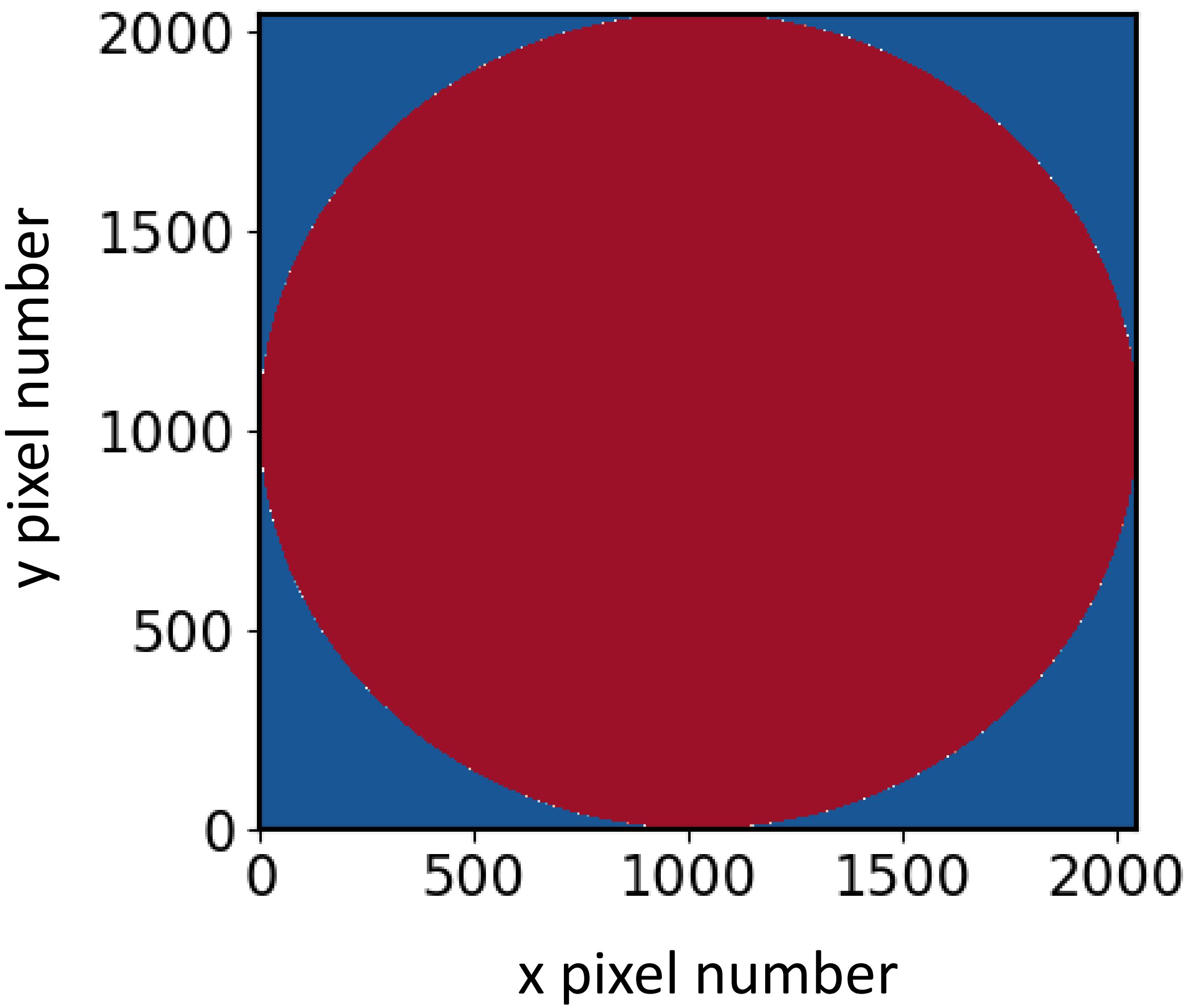

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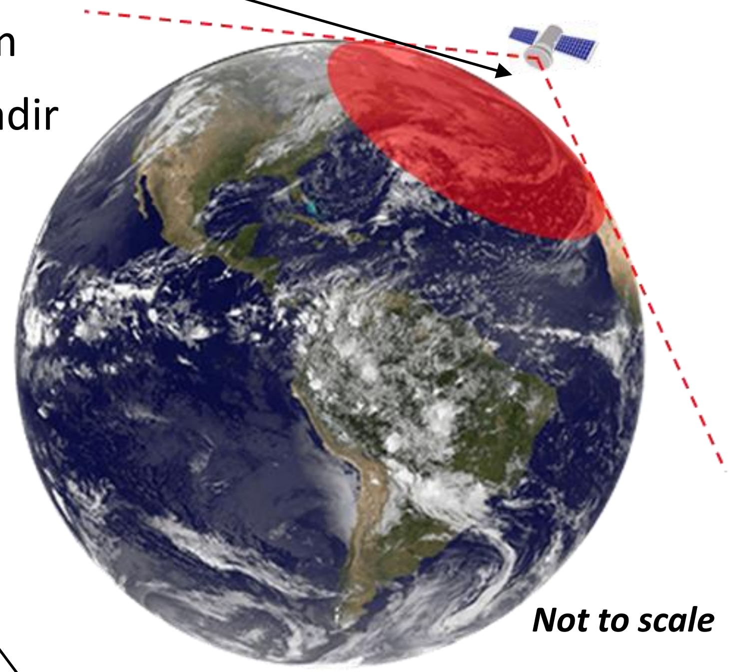


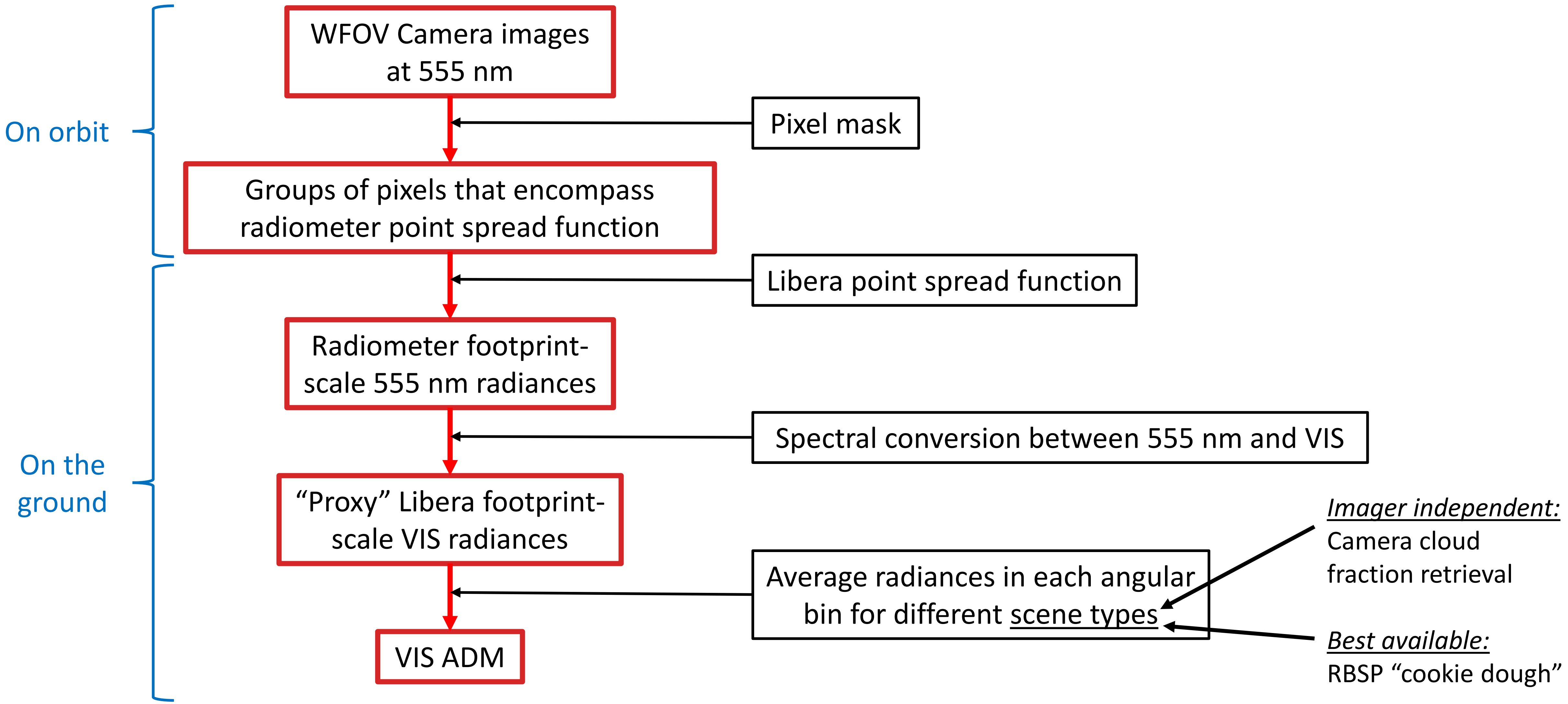
Key requirements:

Radiometric accuracy: 5 %

Uniformity: 1.5 %

$$R_{i,j} = \frac{\pi \overline{I_{i,j}}}{F}$$

2. camera ADMs [shortly after launch]



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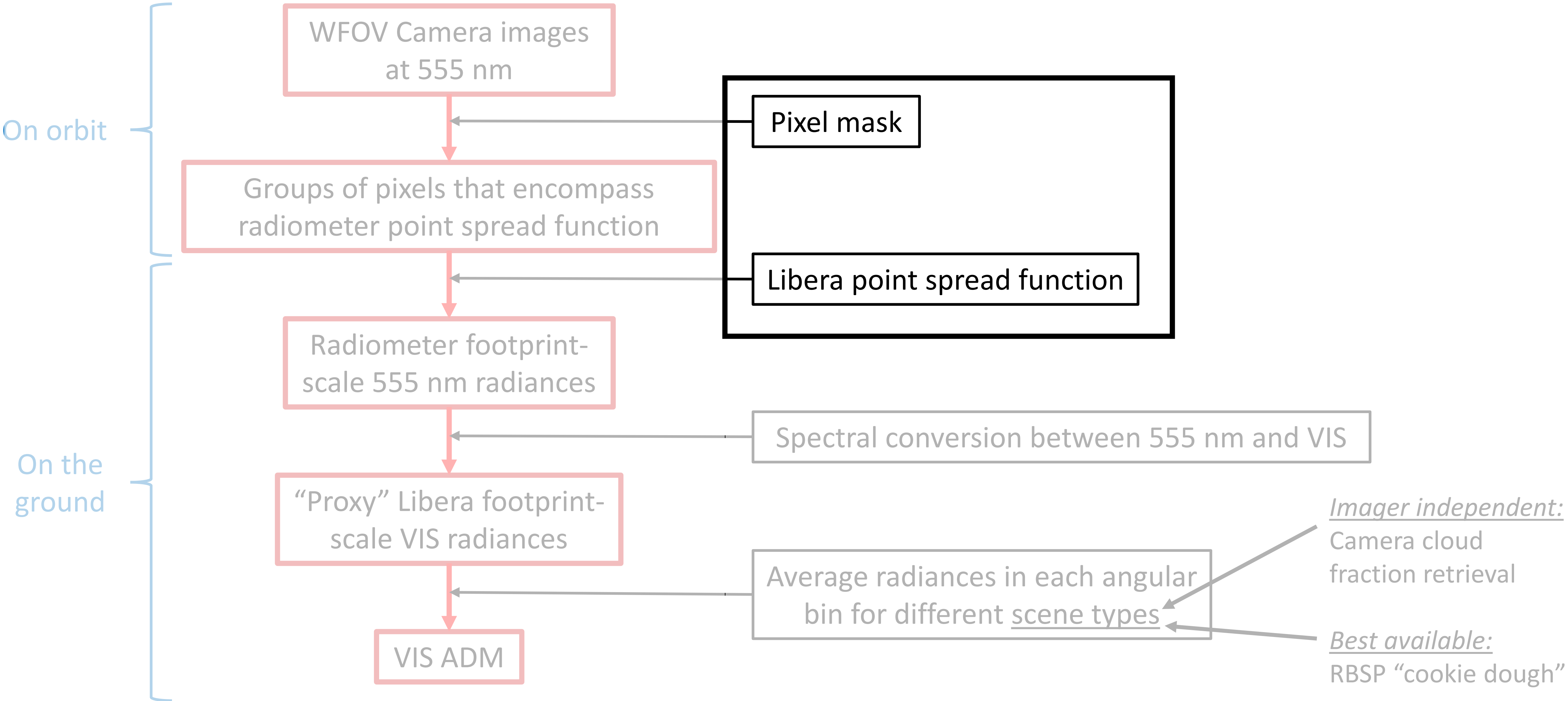
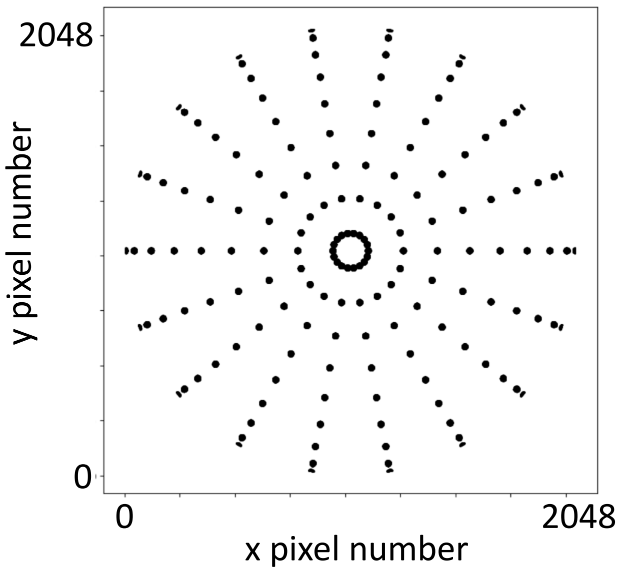


Camera ADM samples



- Data rate limited! Can typically only downlink small fraction of pixel array

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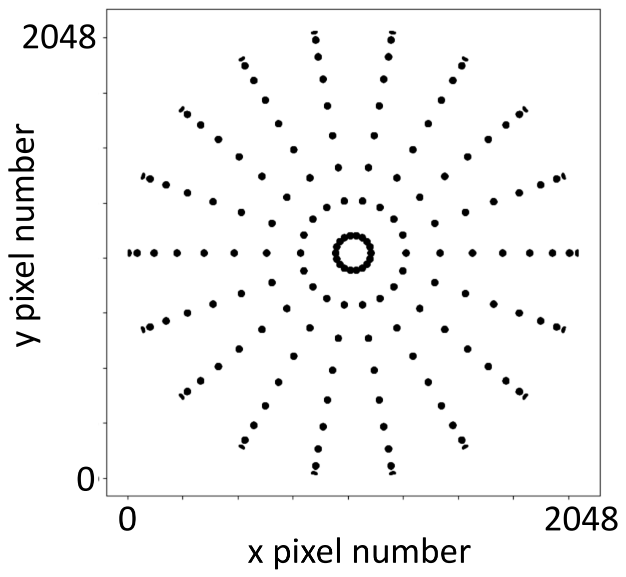

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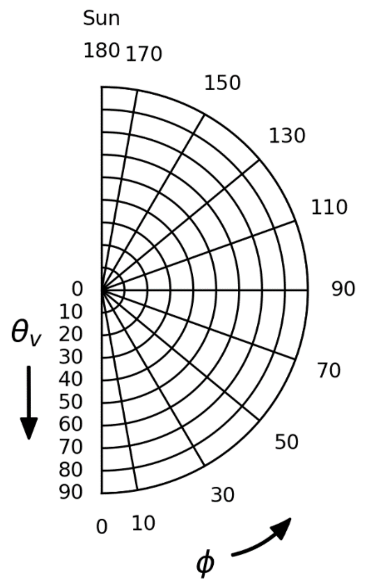
- Select "ADM samples": groups of pixels in each angular bin encompassing Libera PSF

CERES-TRMM angular bins:



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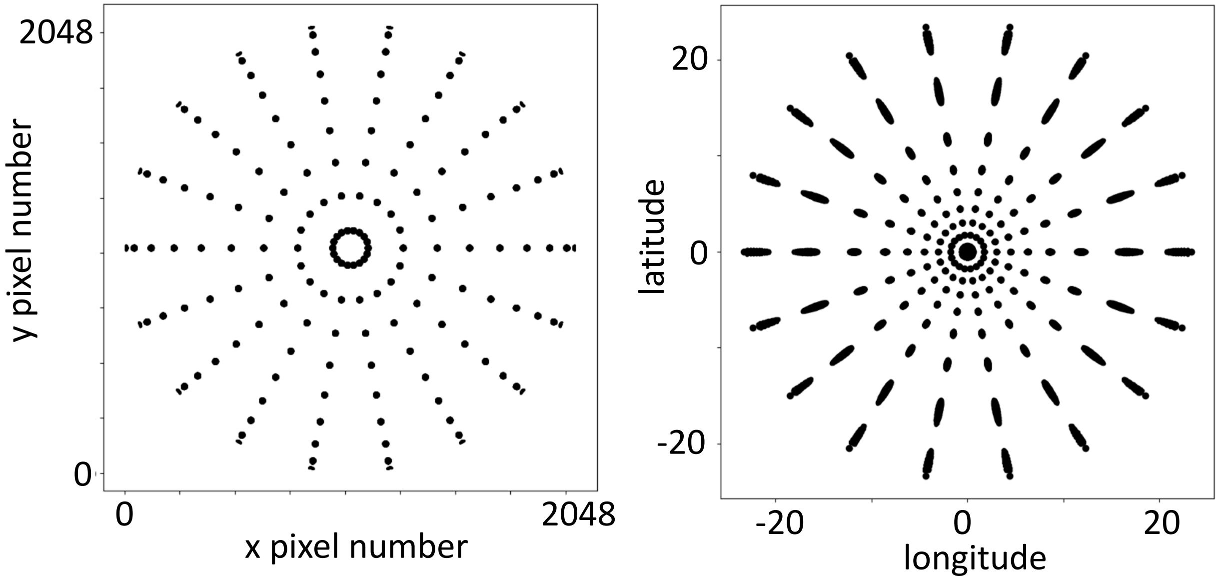

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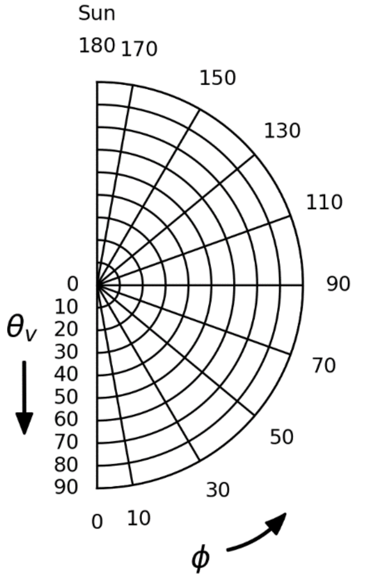

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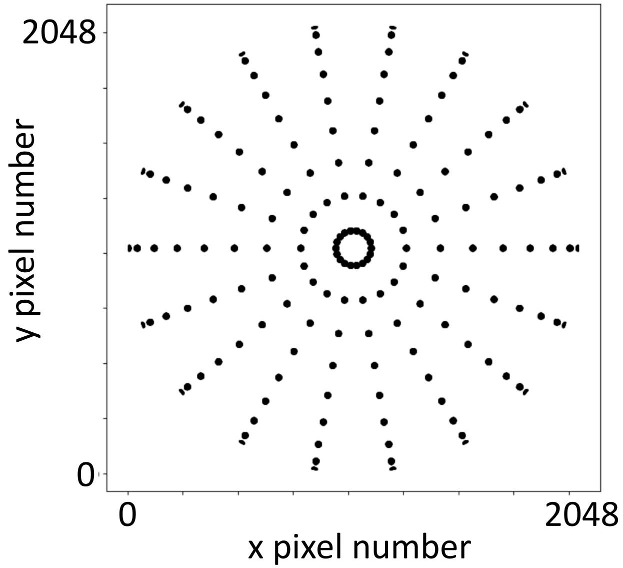

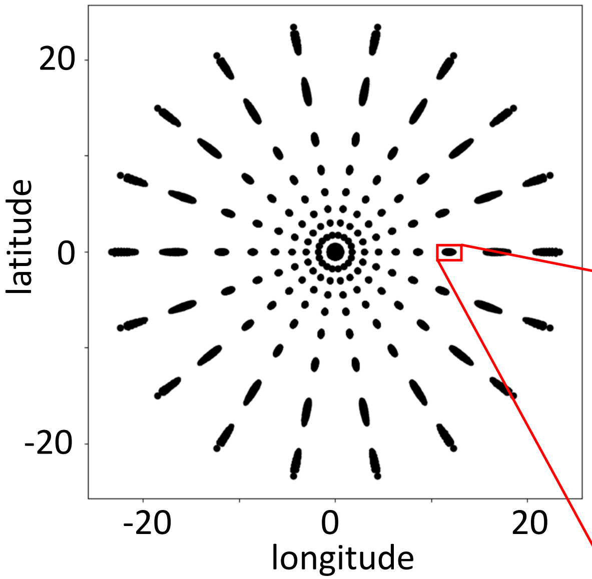

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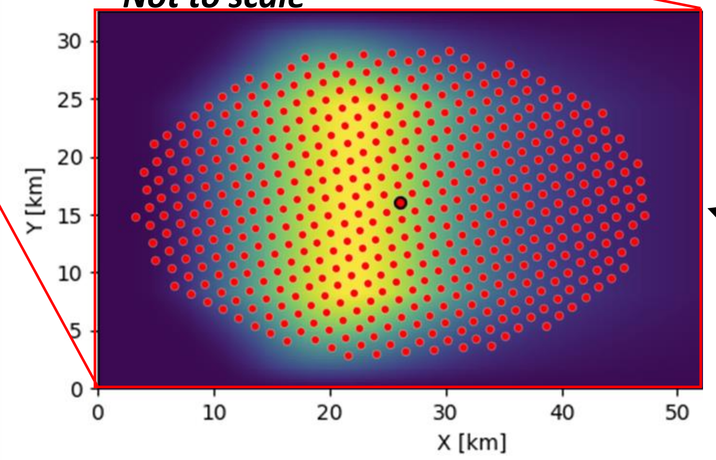
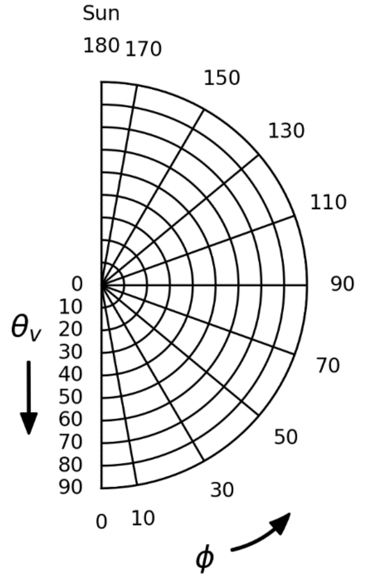


CERES-TRMM angular bins:



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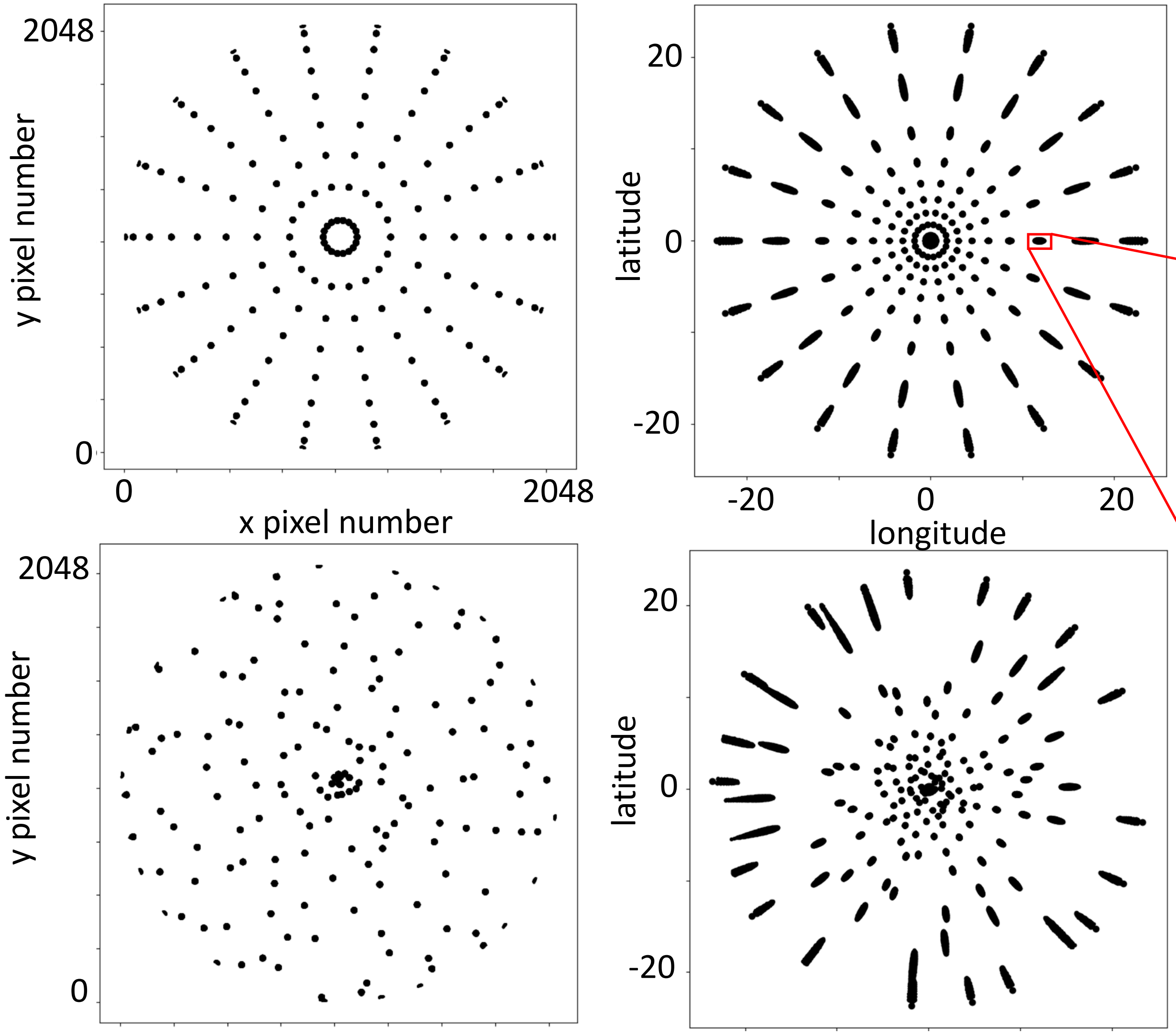
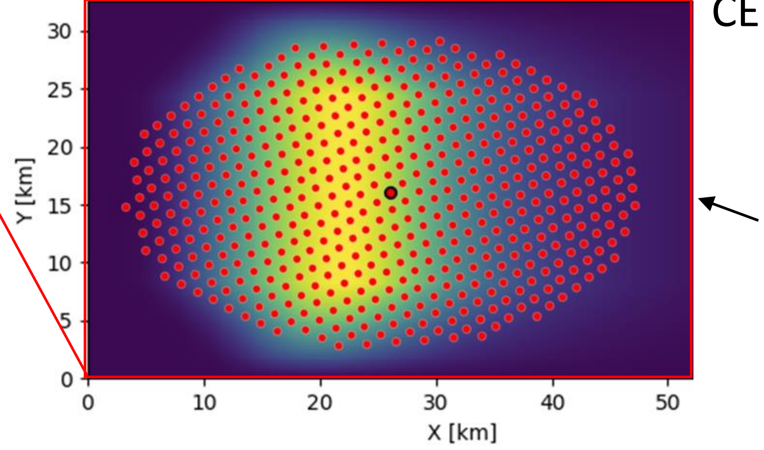
Camera ADM samples

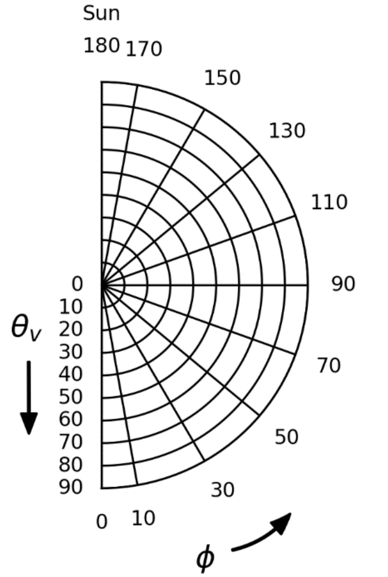


- Data rate limited! Can typically only downlink small fraction of pixel array
- Select “ADM samples”: groups of pixels in each angular bin encompassing Libera PSF

Not to scale

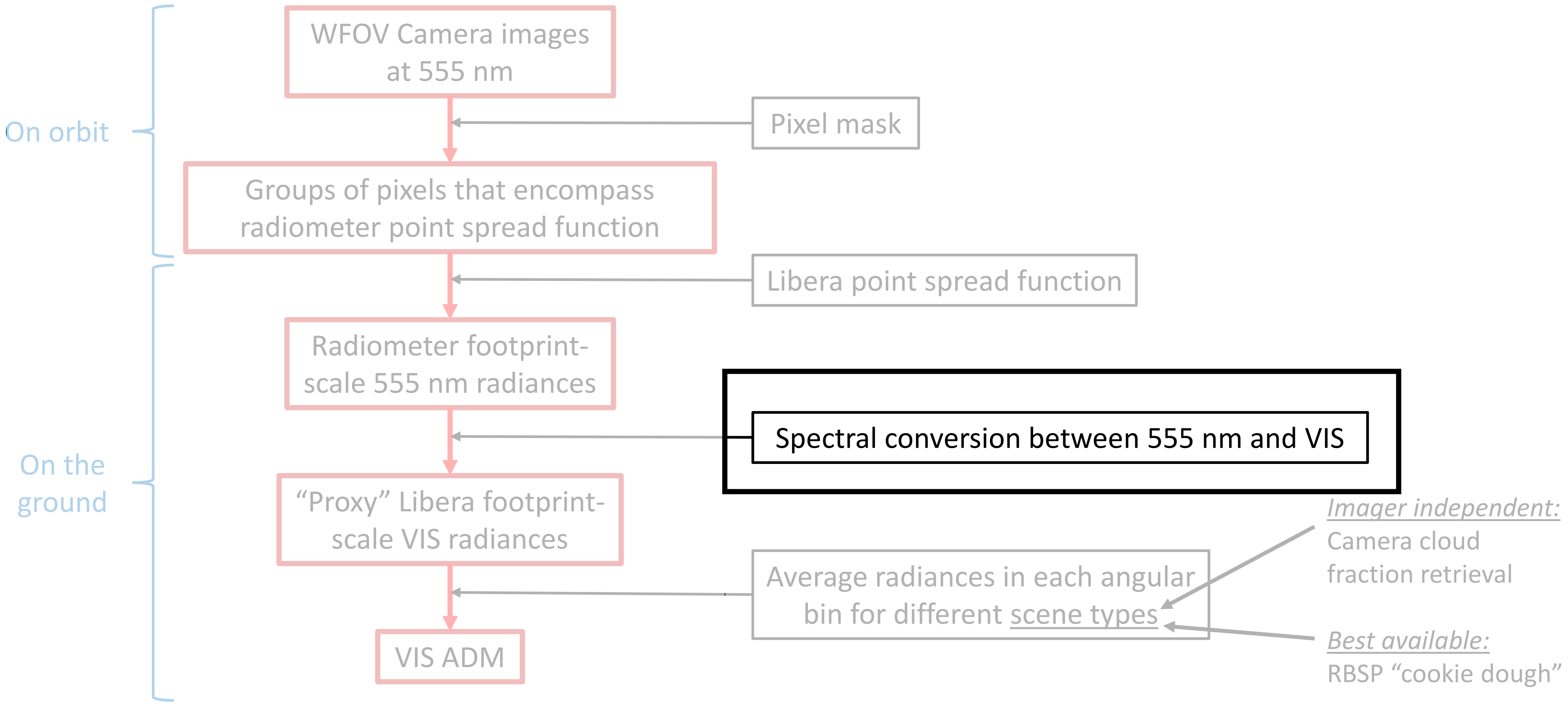


CERES-TRMM angular bins:



- We do not just want to sample the center of the angular bins: randomization

2. camera ADMs [shortly after launch]



555nm – VIS relationship

- Camera wavelength acts as a proxy for one of the split channels

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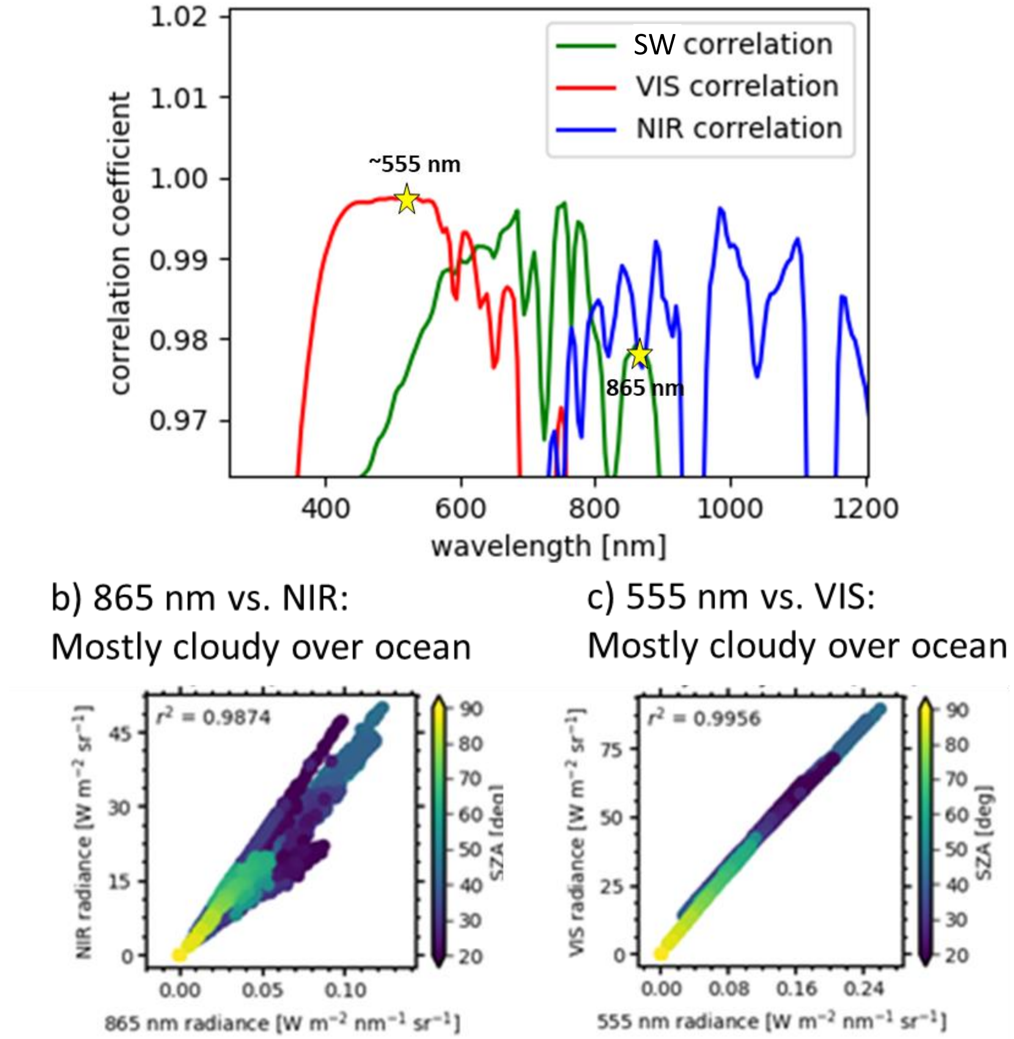
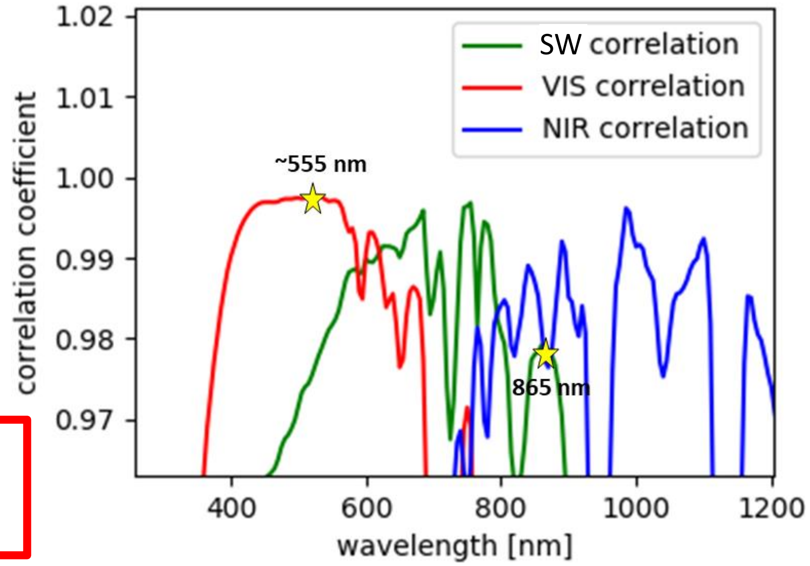
- CLARREO OSSE data (*Feldman et al., JGR [2011]*) suggests mid-visible wavelength is optimal for Libera VIS band

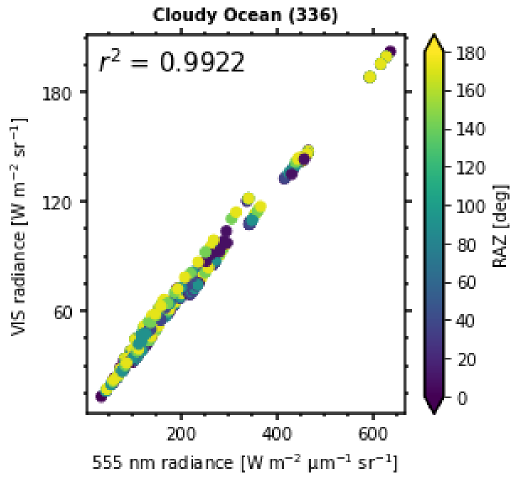


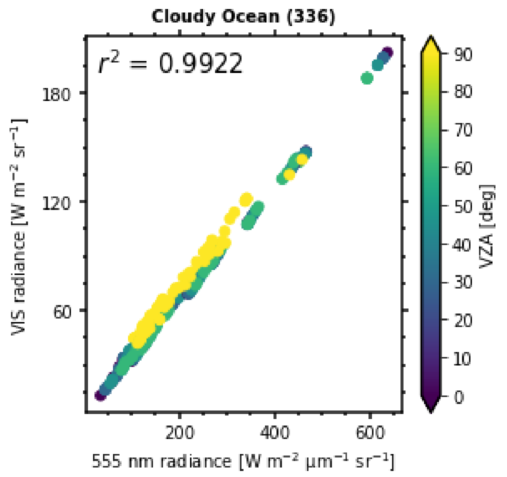
555nm – VIS relationship

- Camera wavelength acts as a proxy for one of the split channels
- CLARREO OSSE data (*Feldman et al., JGR [2011]*) suggests mid-visible wavelength is optimal for Libera VIS band
- Preliminary radiative transfer indicates angular distribution of mid-visible and VIS are almost identical



Need to demonstrate spectral variations in angular distribution are consistent *statistically* within all scene types – updated OSSEs coming soon!

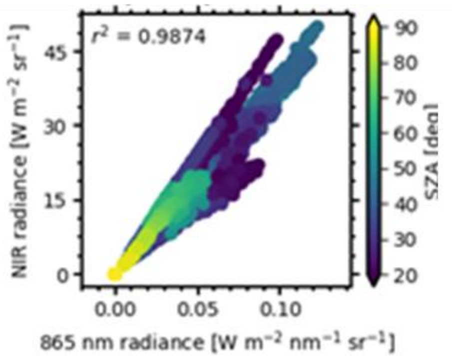




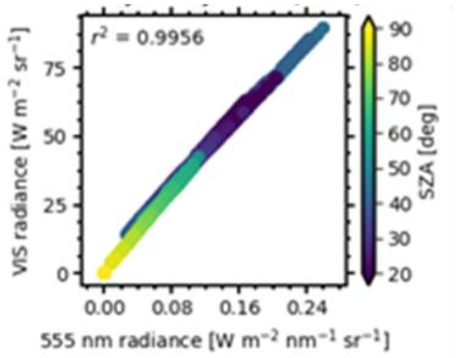
Credit:
Josh Mauss

Dataset from:
Loeb et al., JAM [2001]

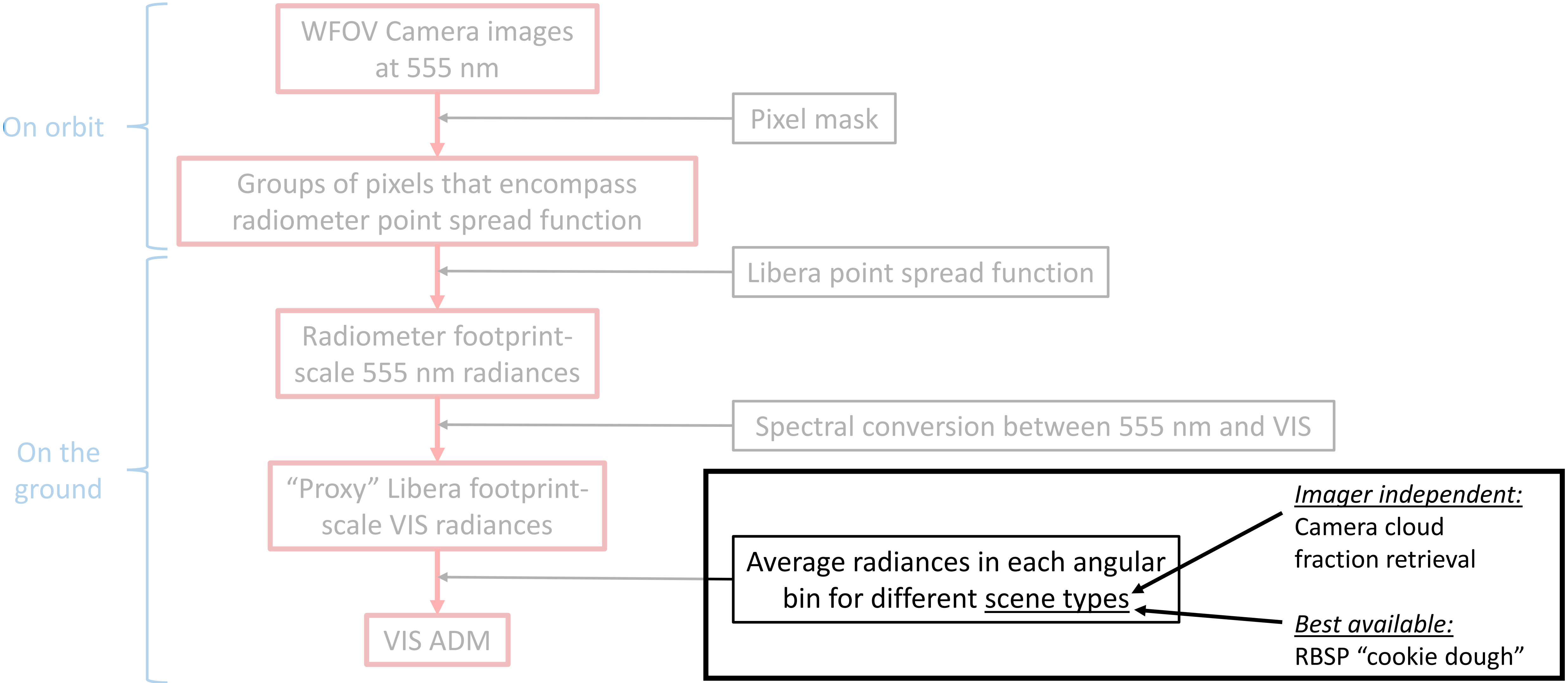
b) 865 nm vs. NIR:
Mostly cloudy over ocean



c) 555 nm vs. VIS:
Mostly cloudy over ocean



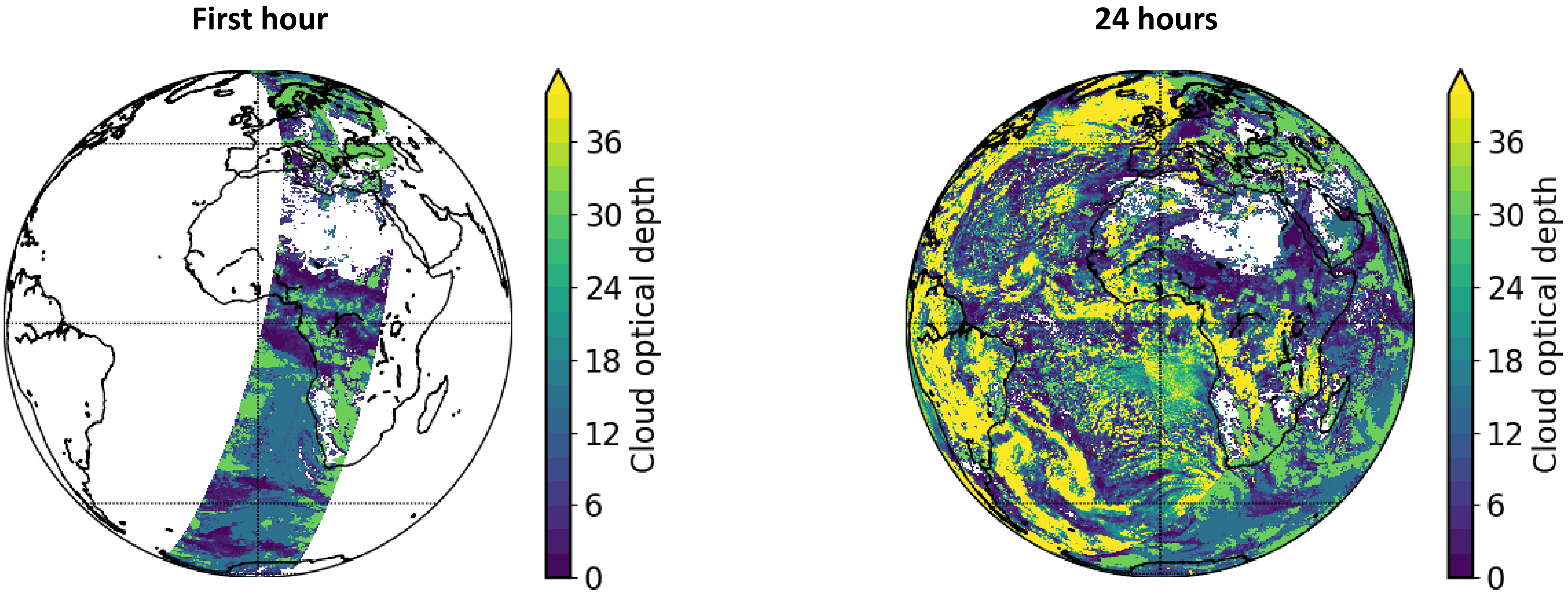
2. camera ADMs [shortly after launch]



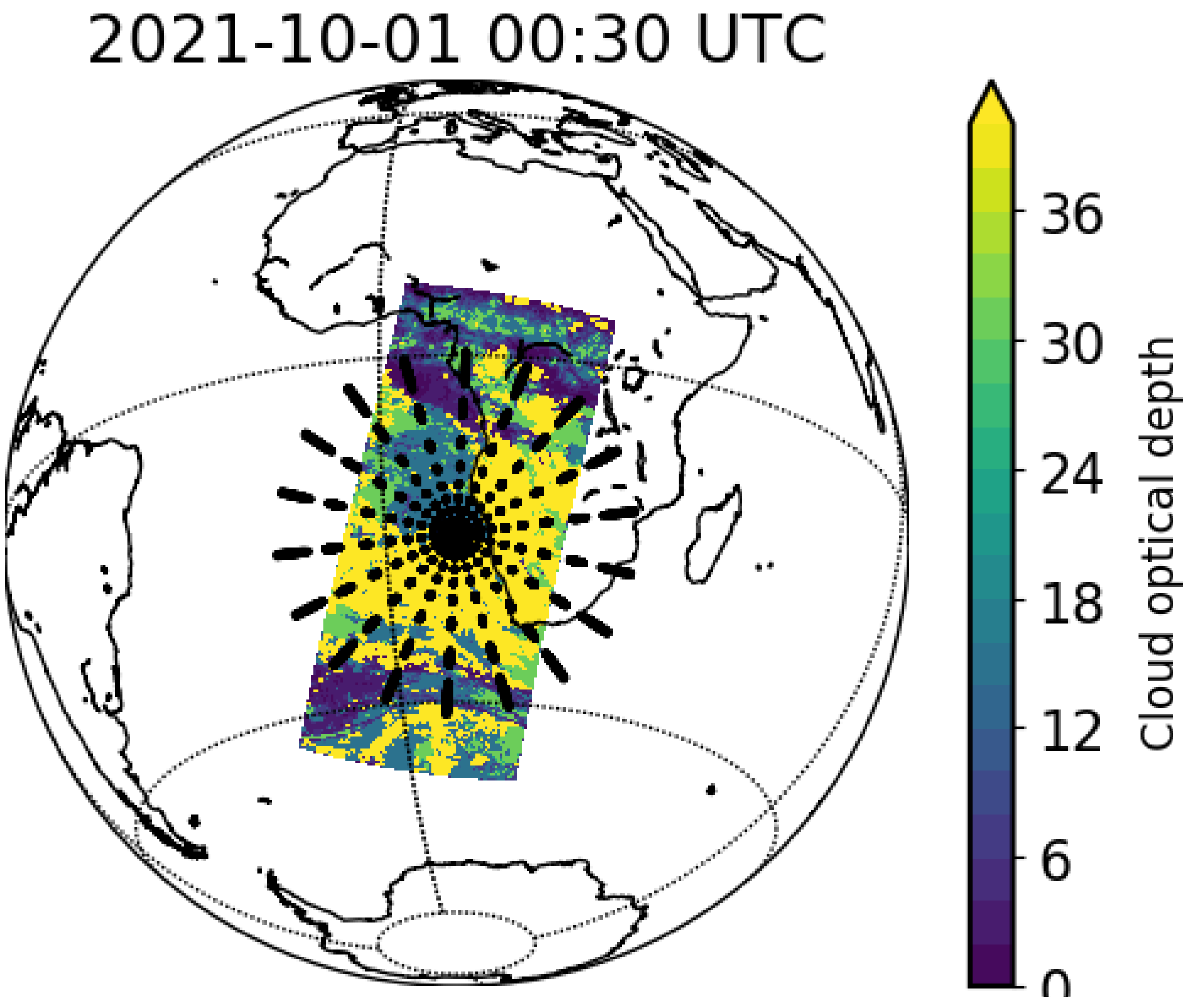
Angular sampling: Let's use CERES "cookie dough"

"We use every fourth VIIRS imager pixel and every other scan line in processing."

NOAA 20 (JPSS-1) 1st October 2021

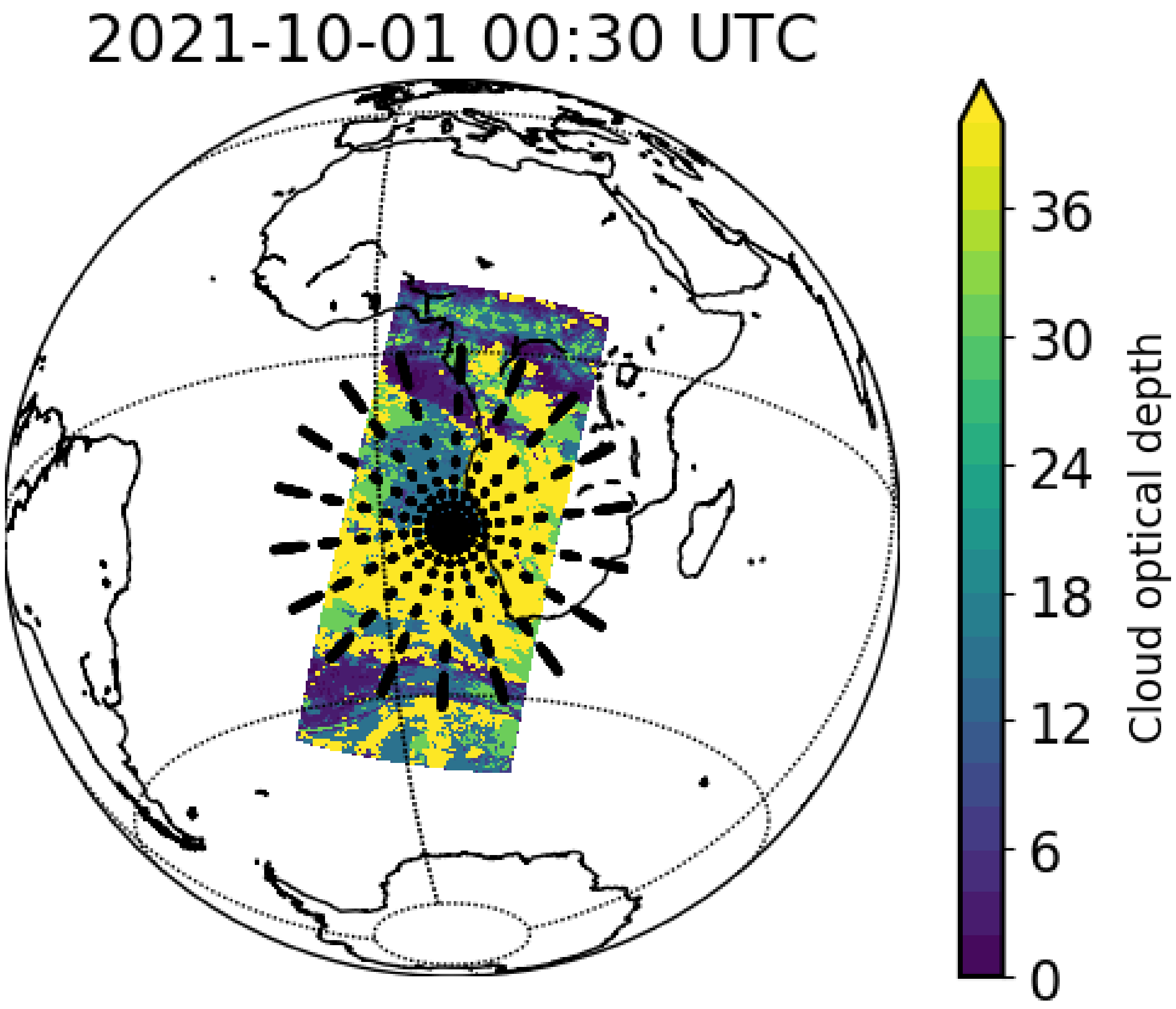


Camera sampling projected onto cookie dough



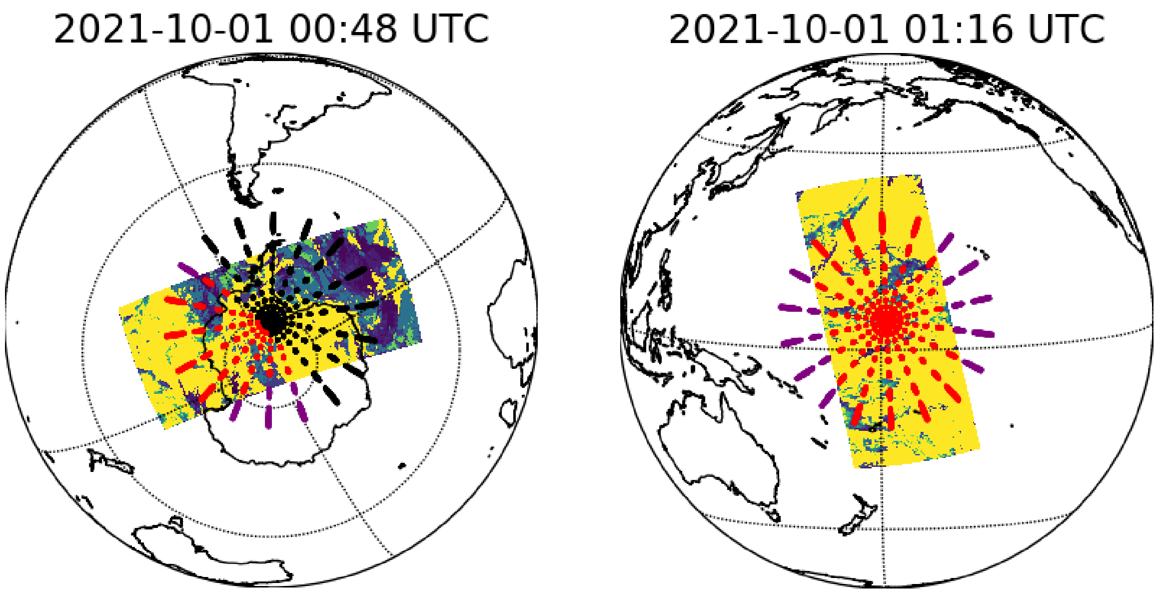
- Select cookie dough +/- 9 min of camera observation time (~15 min for satellite to traverse camera FOV)

Camera sampling projected onto cookie dough

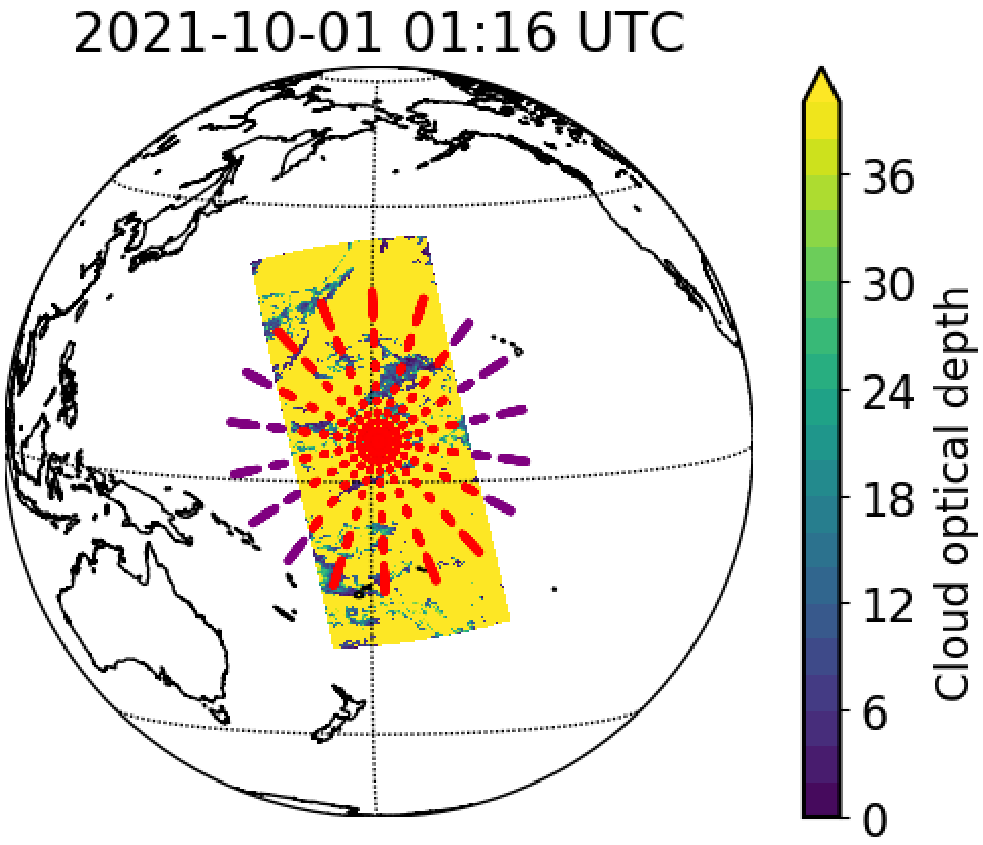


- Select cookie dough +/- 9 min of camera observation time (~15 min for satellite to traverse camera FOV)

Key
- Night ADM sample (not downlinked!)
- Day ADM sample, outside VIIRS swath
- Day ADM sample, co-located with VIIRS swath



ADM sample scene type from cookie dough



- For each pixel: surface type and cloud fraction from nearest interpolation to cookie dough
- ADM sample surface type: mode, cloud fraction: mean

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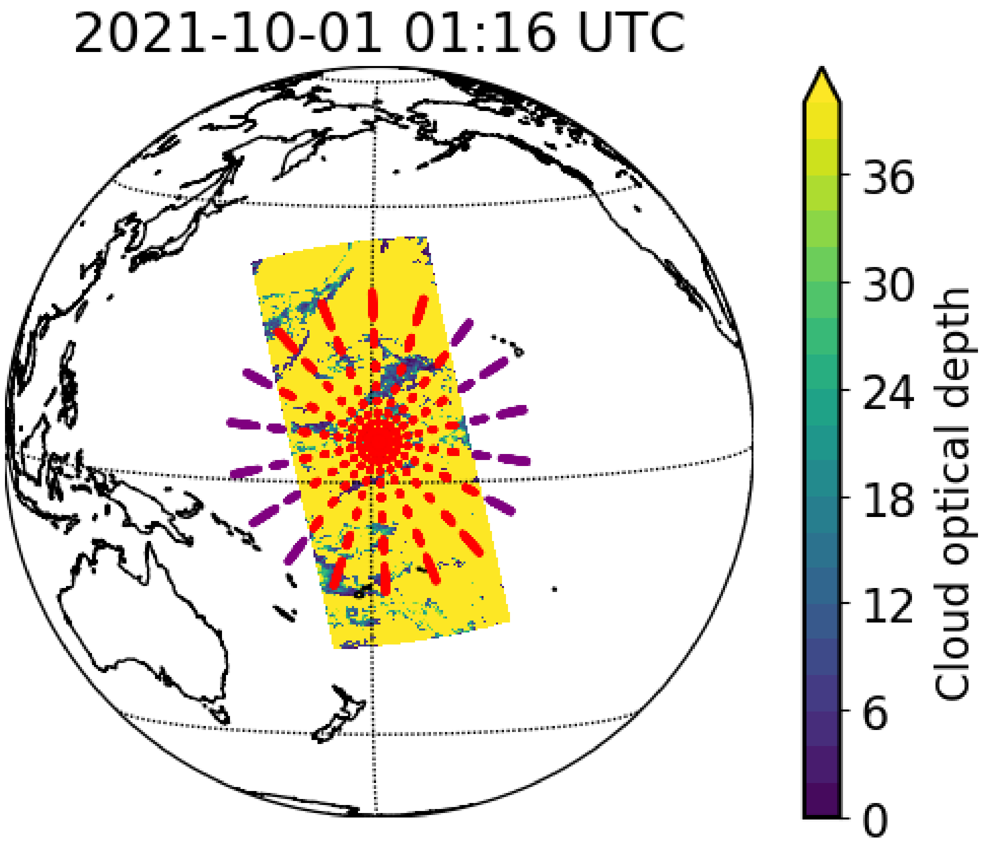
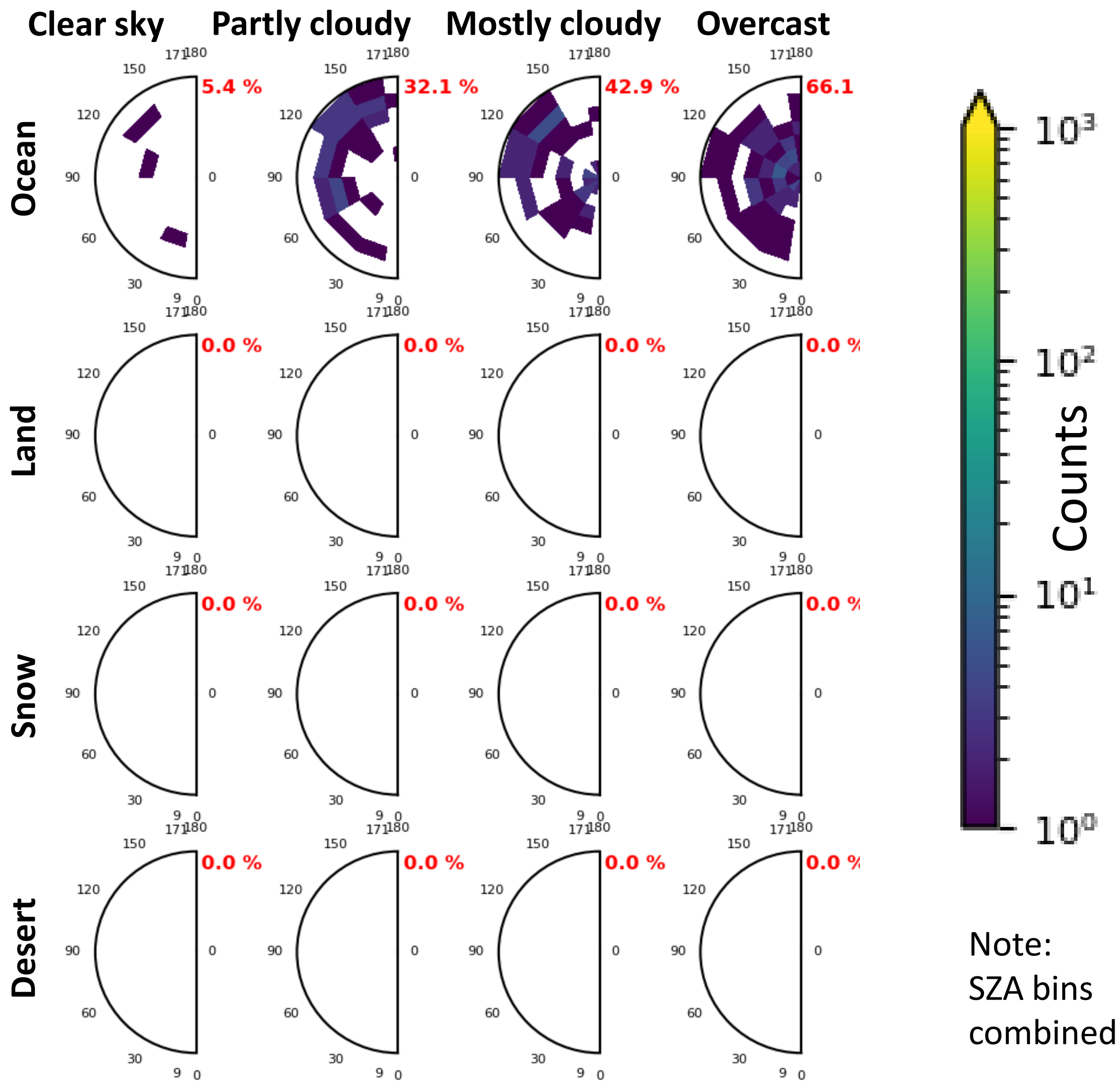
ADM sample scene type from cookie dough



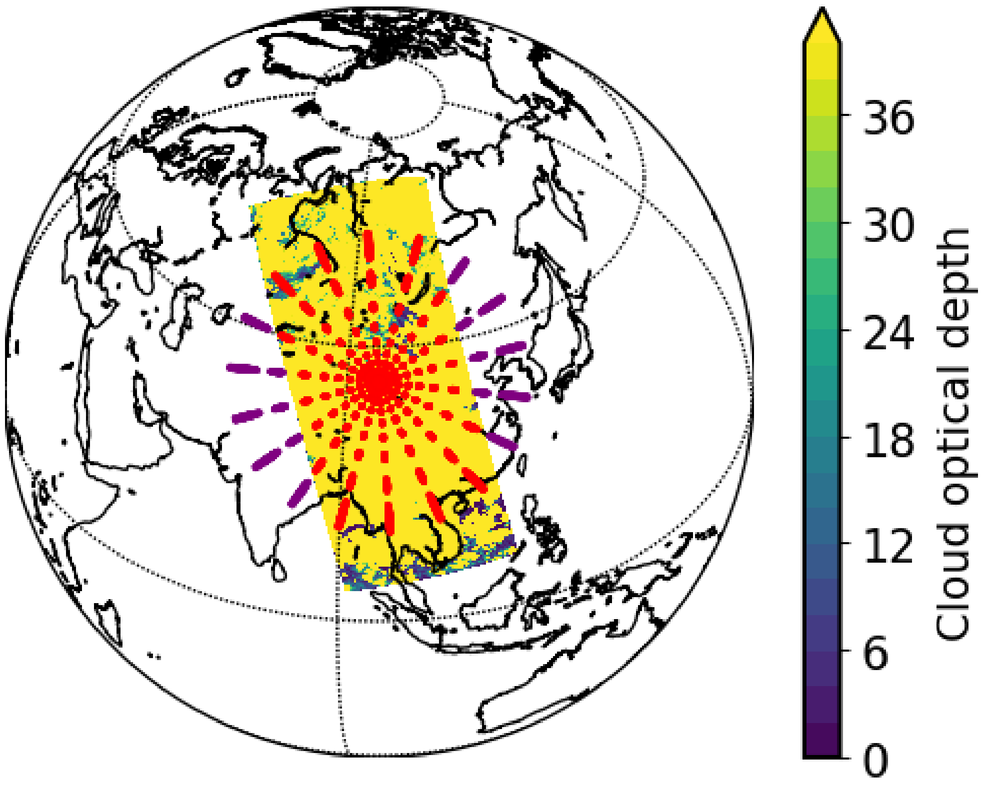


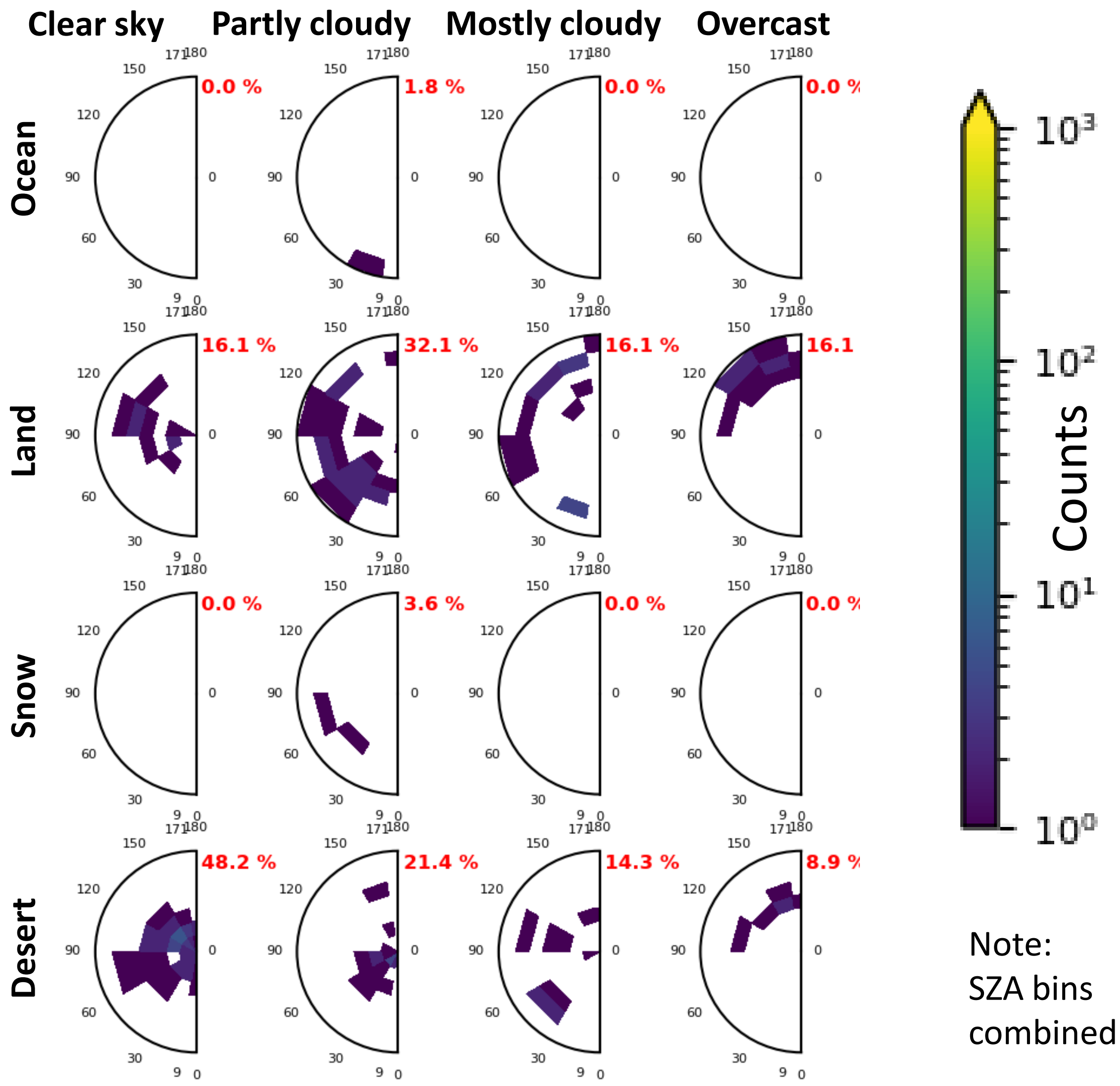
Note:
SZA bins
combined

- For each pixel: surface type and cloud fraction from nearest interpolation to cookie dough
- ADM sample surface type: mode, cloud fraction: mean

ADM sample scene type from cookie dough

2021-10-01 06:30 UTC





Note:
SZA bins
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- For each pixel: surface type and cloud fraction from nearest interpolation to VIIRS
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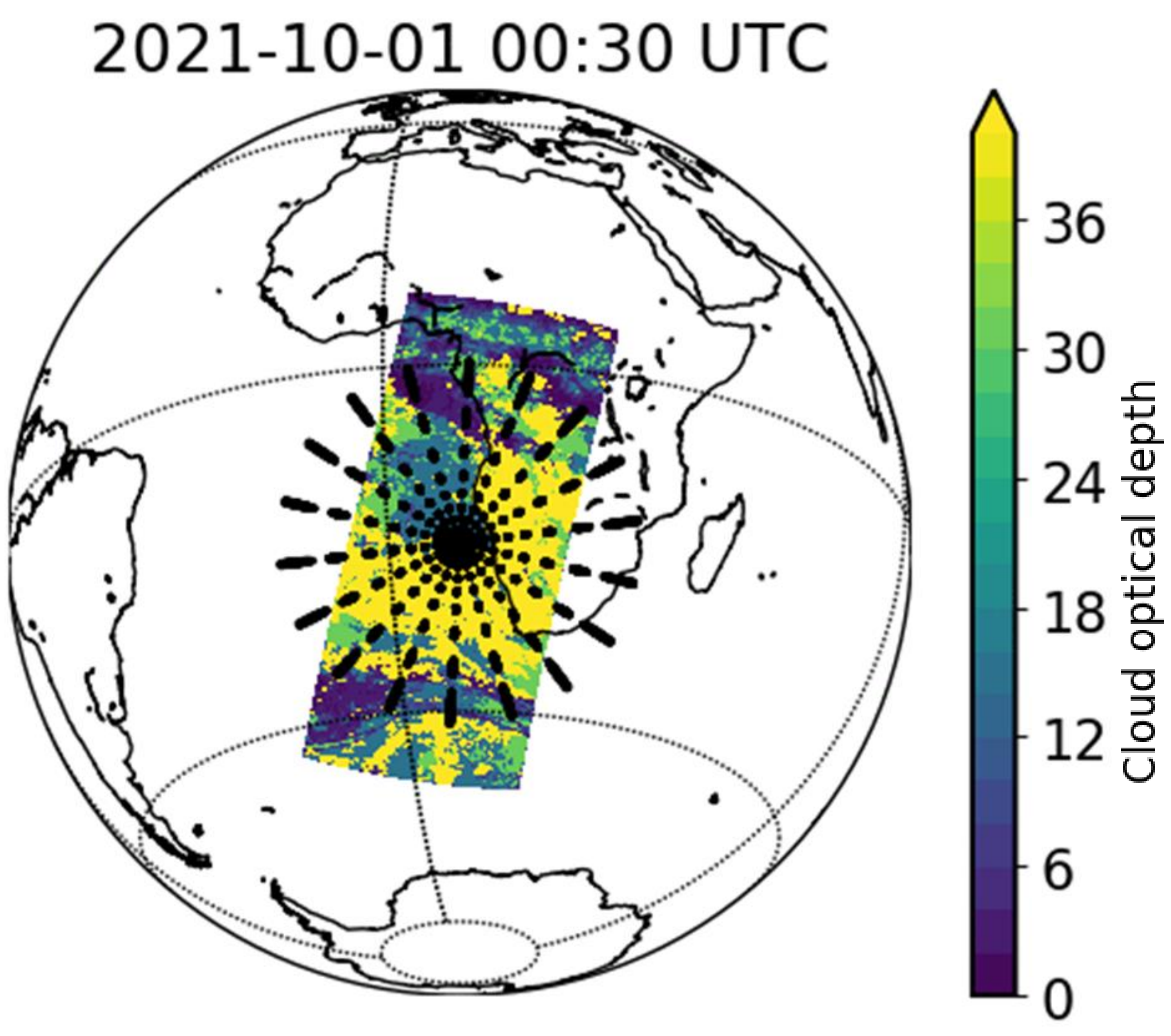
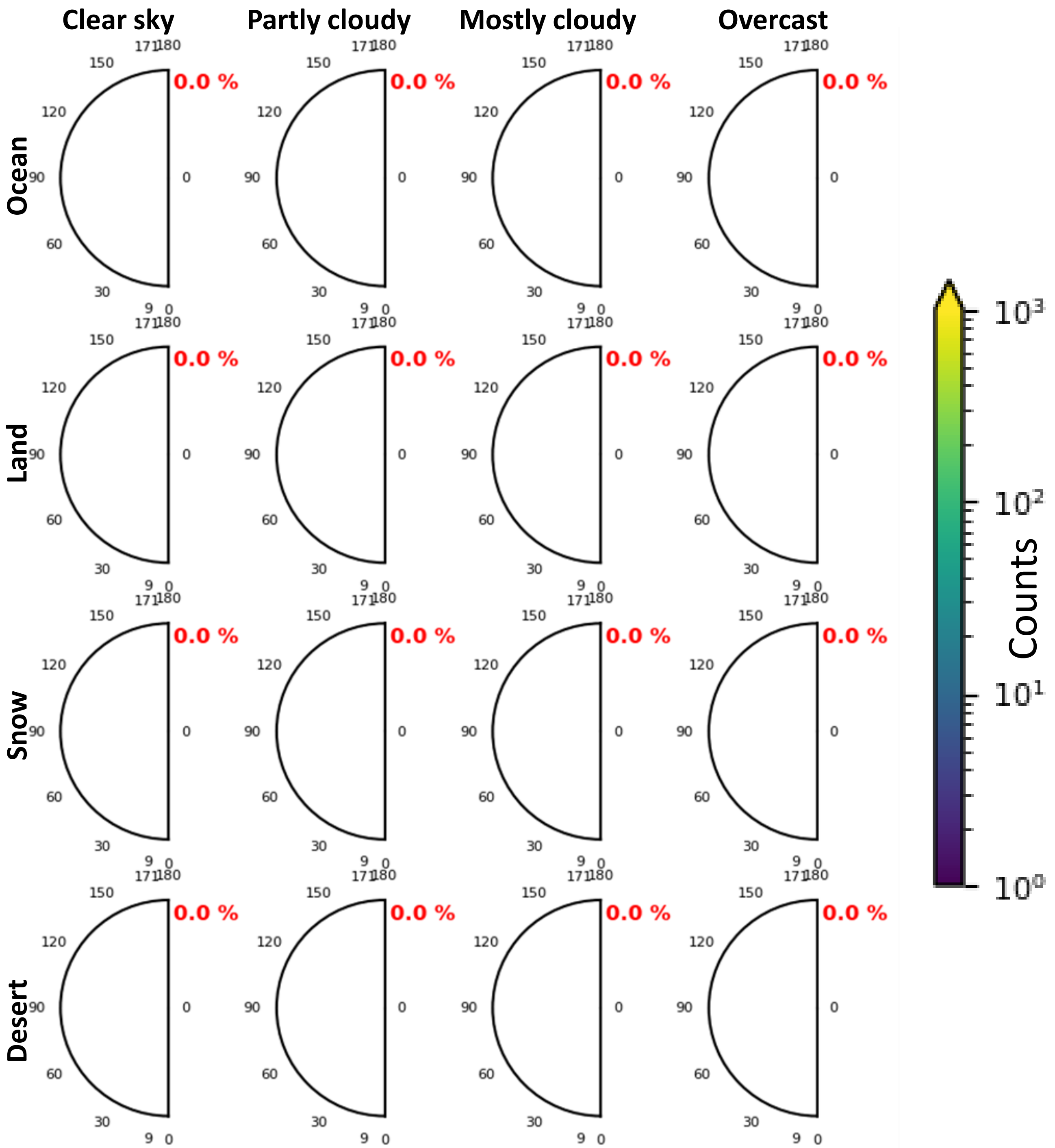
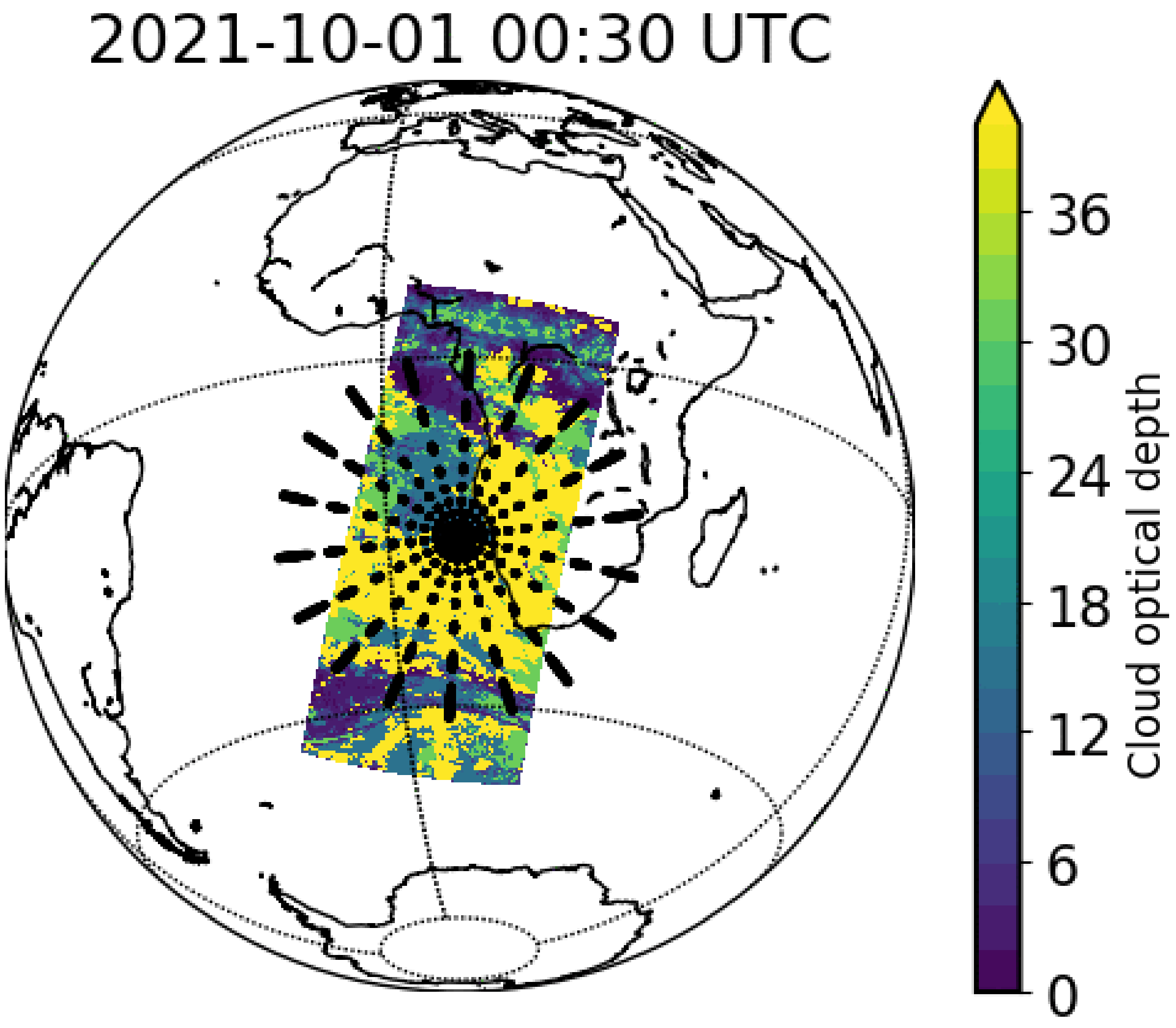


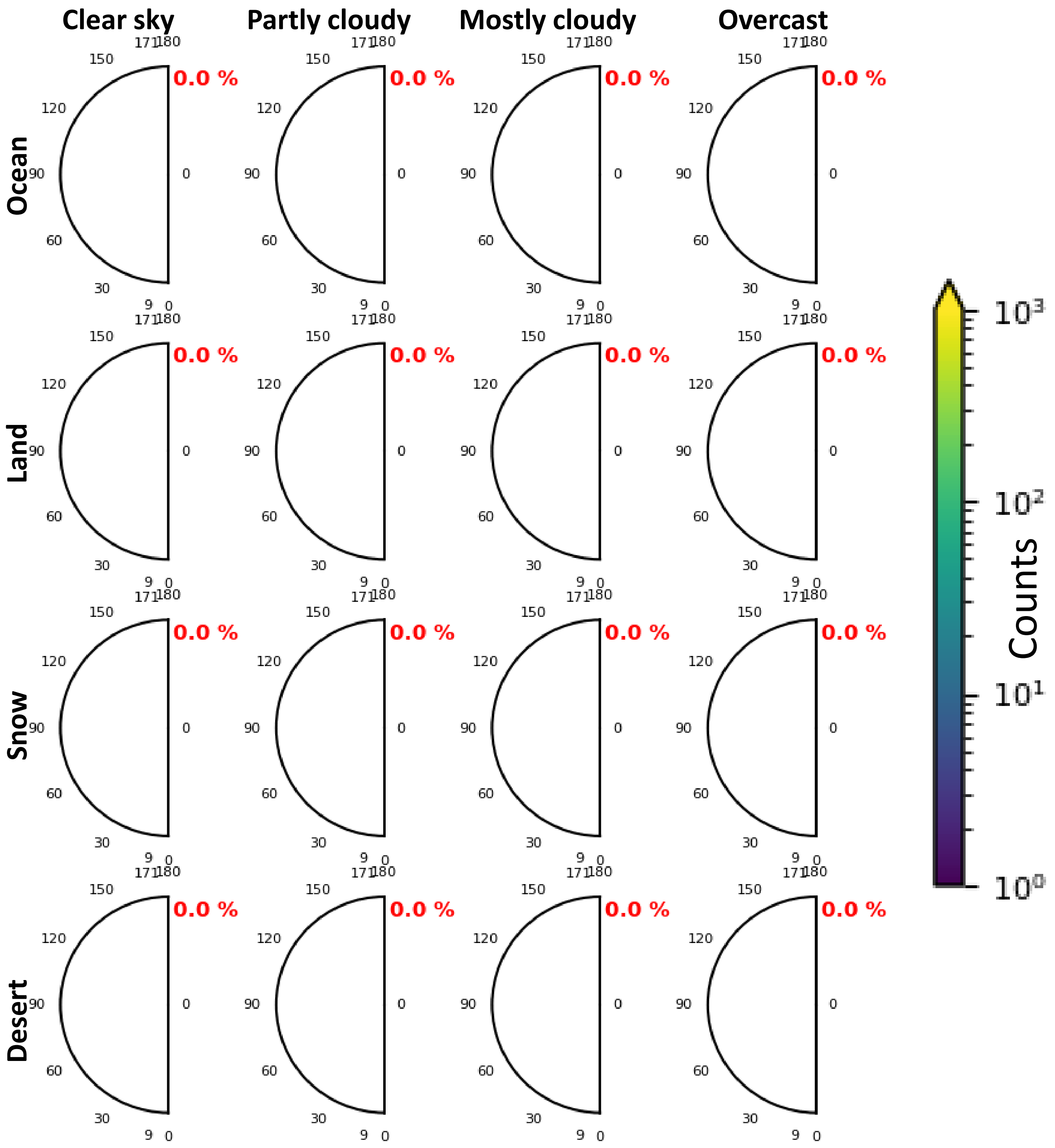


Key

Gristey et al. (in prep.)

- Night ADM sample
- Day ADM sample, outside VIIRS swath
- Day ADM sample, added to count





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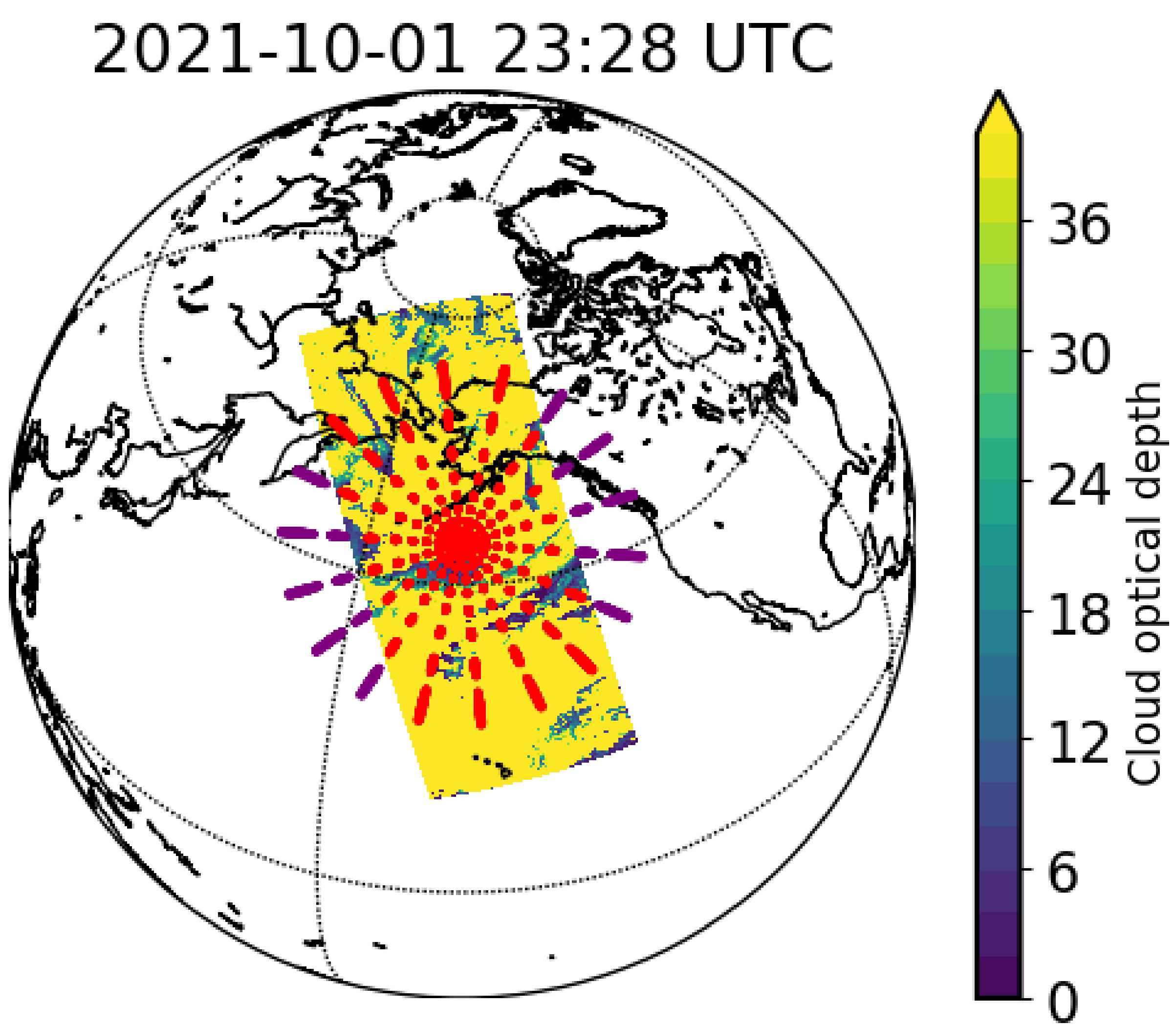

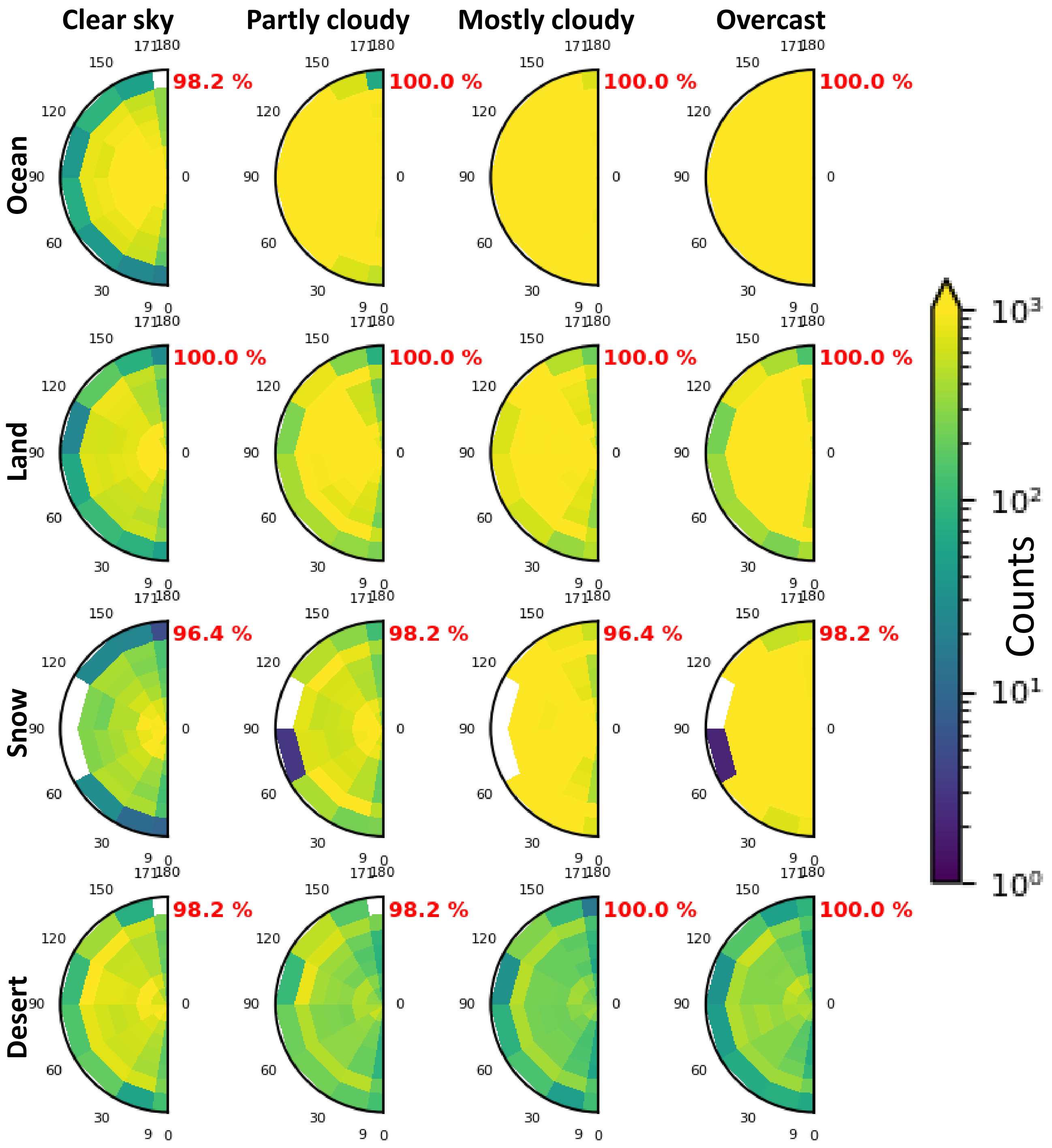

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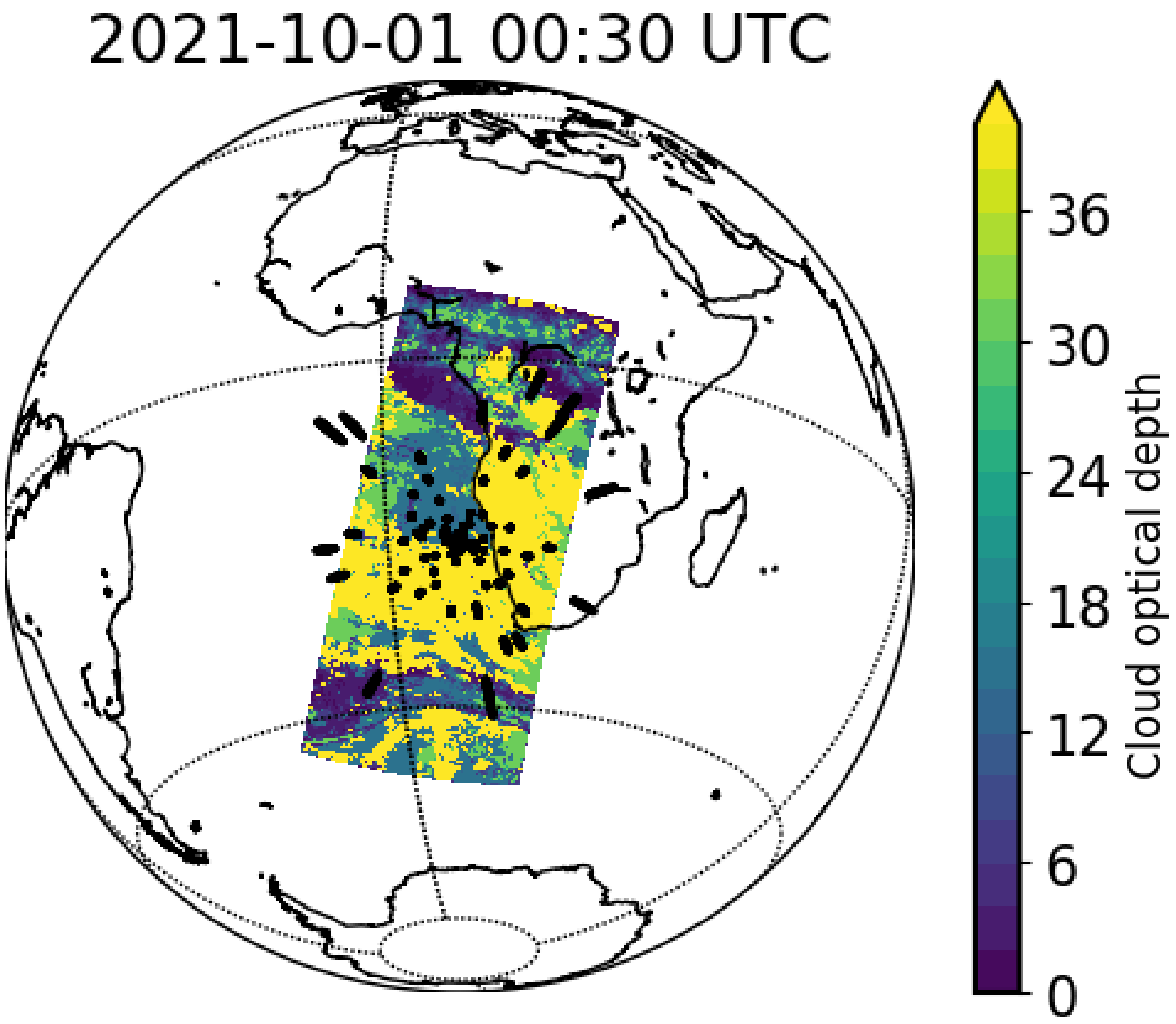

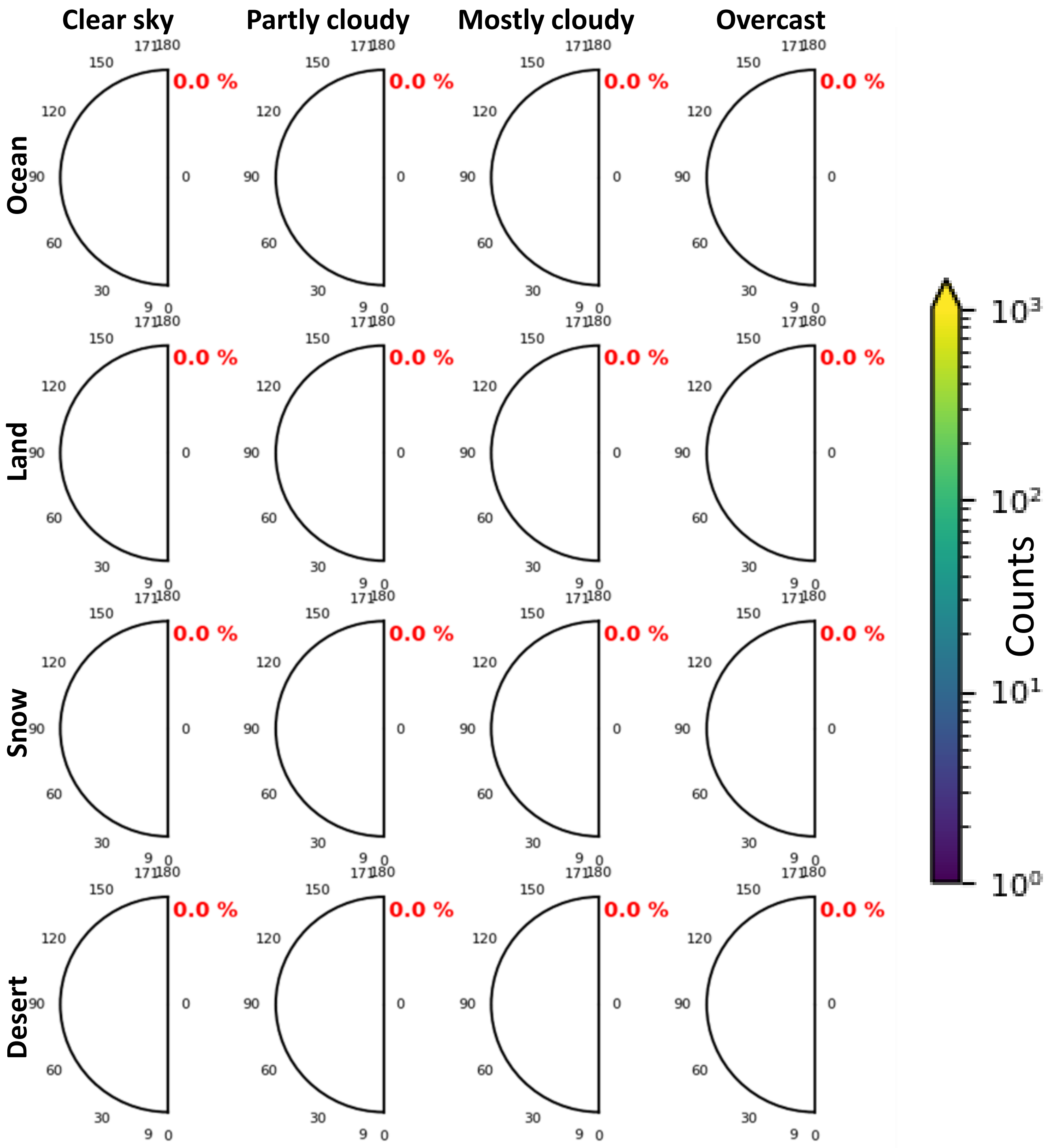

Gristey et al. (in prep.)

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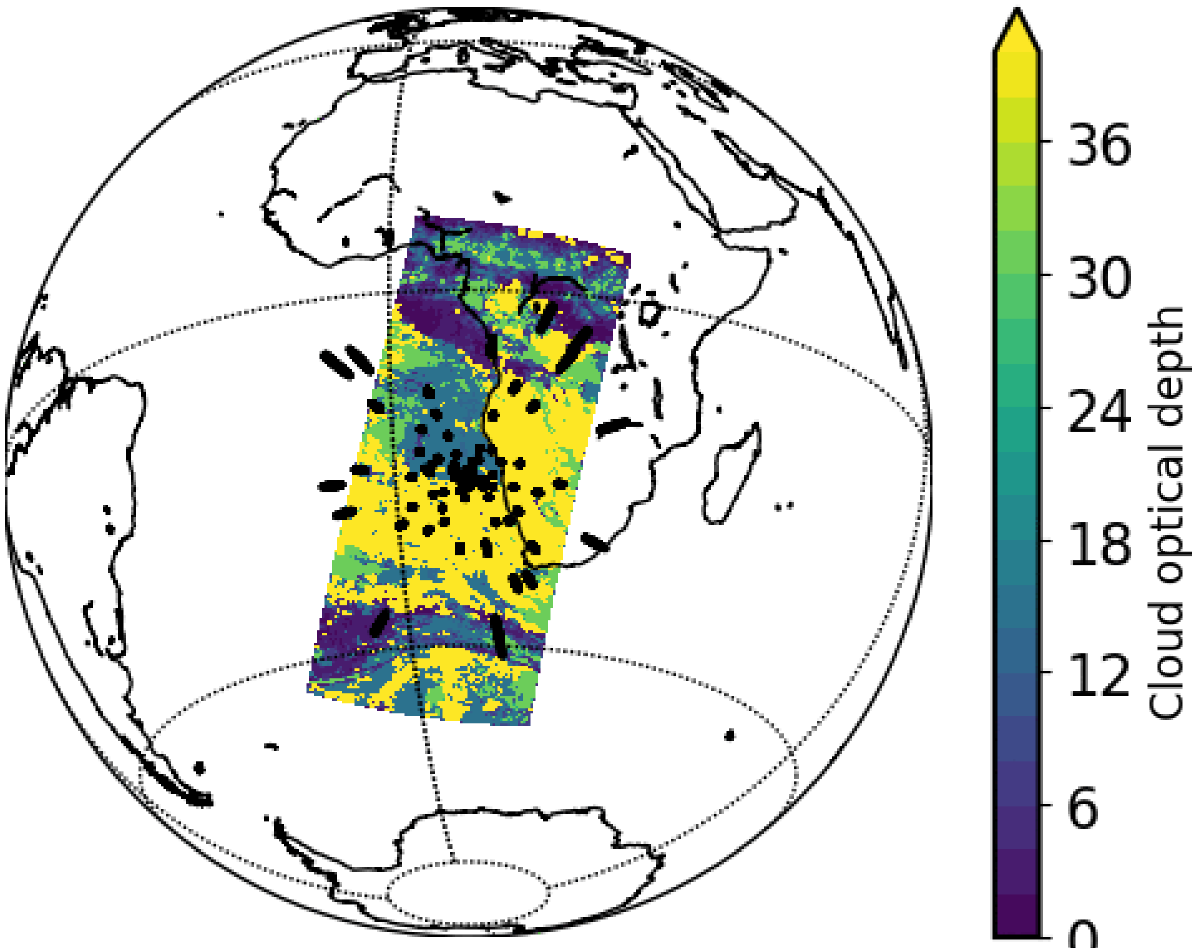
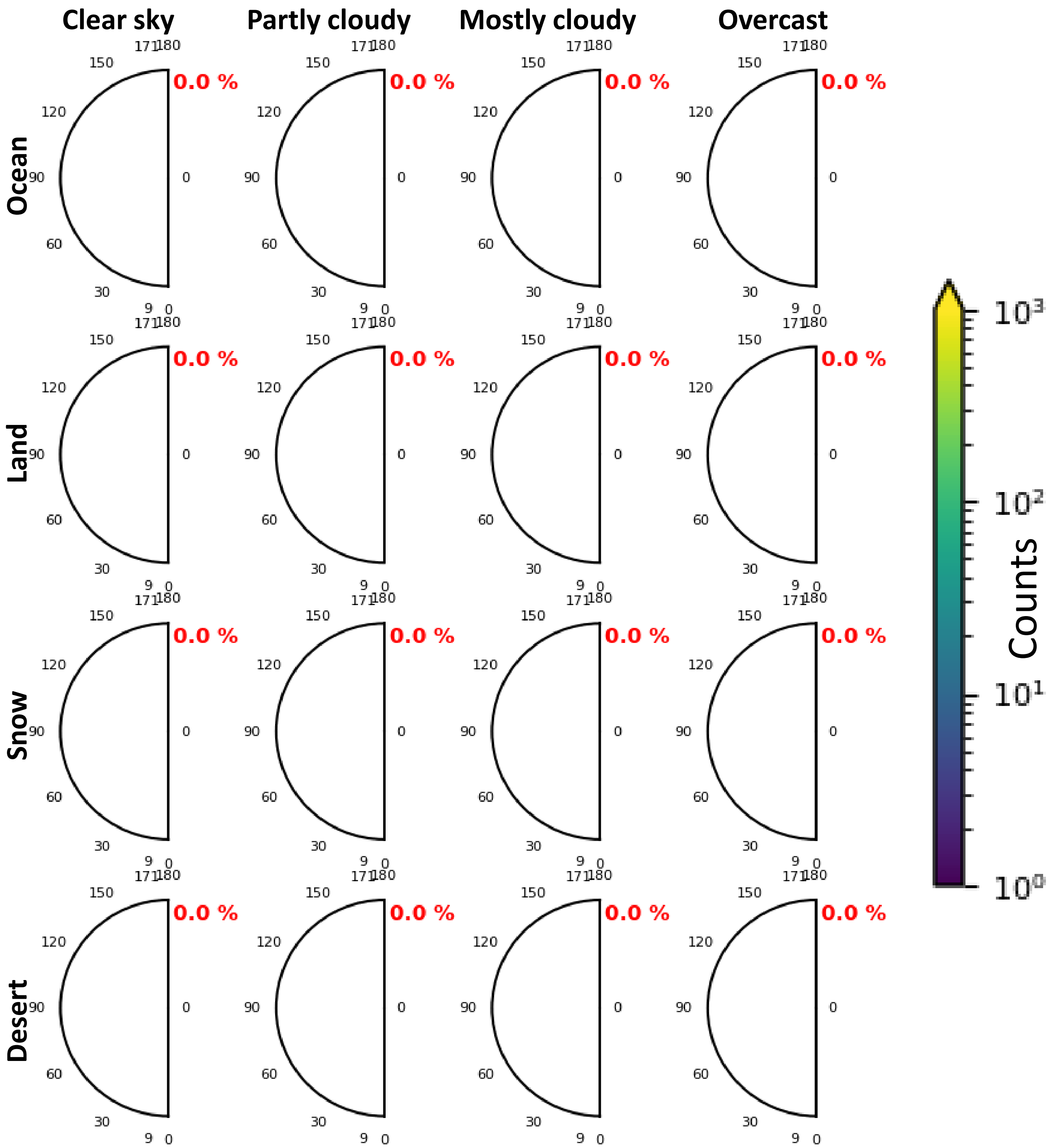
2021-10-01 00:30 UTC





Gristey et al. (in prep.)

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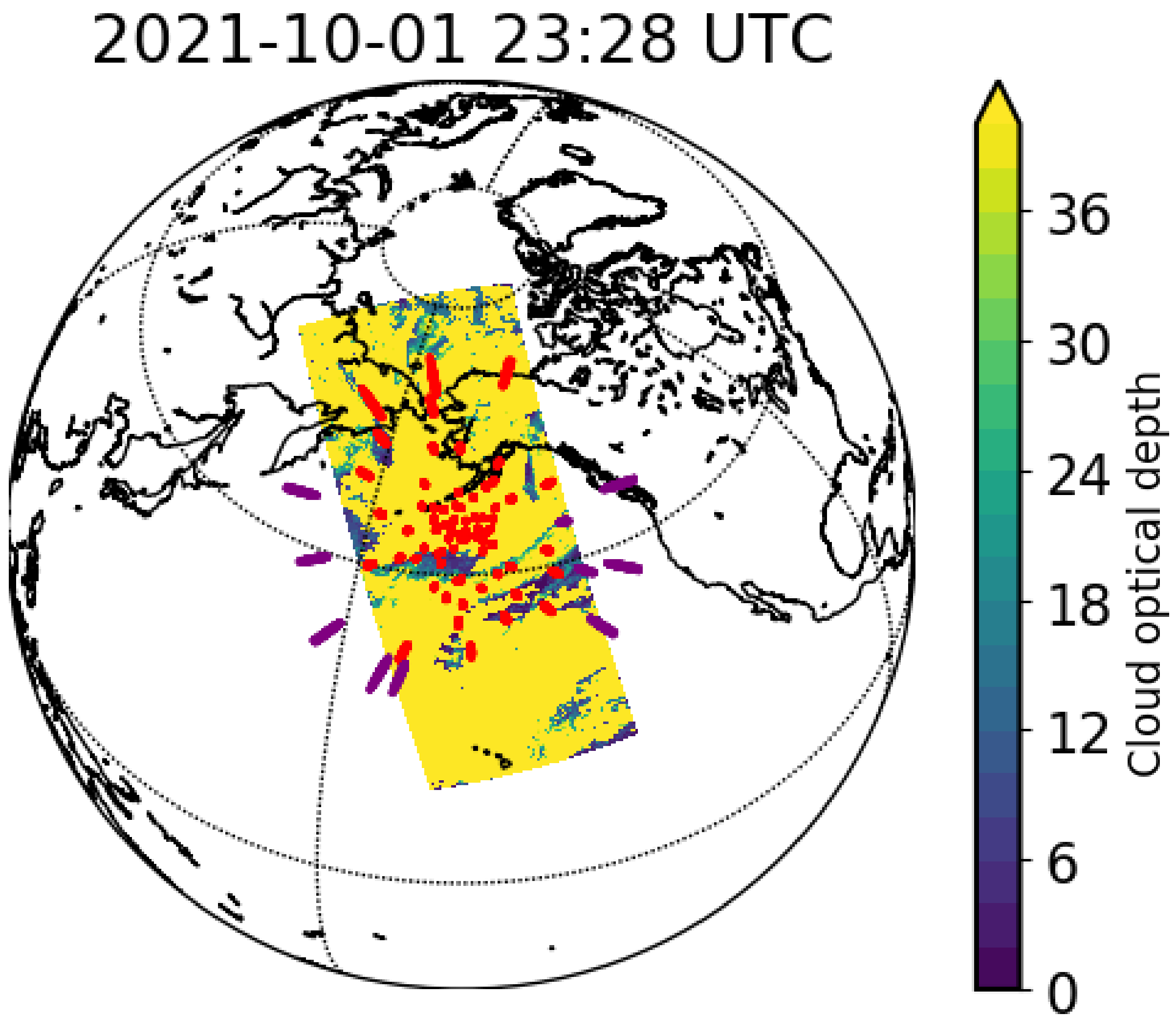

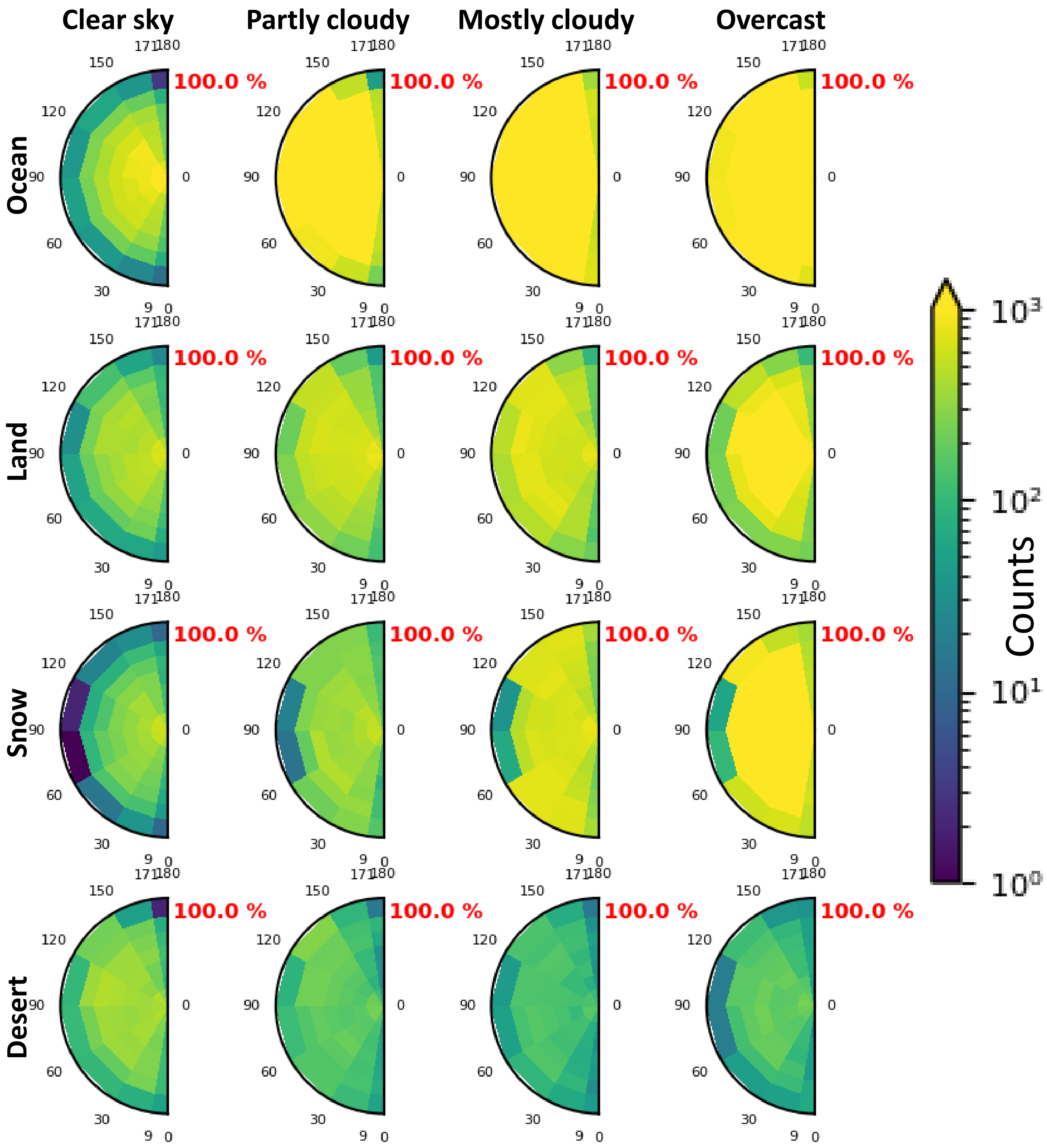

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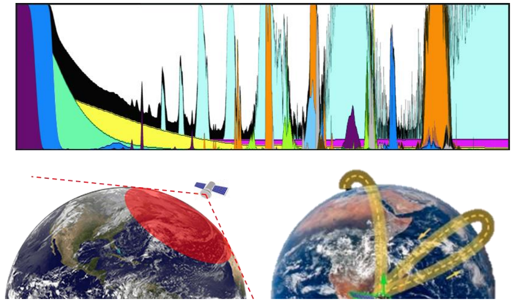
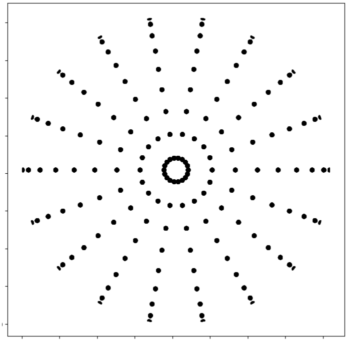
Summary and conclusions

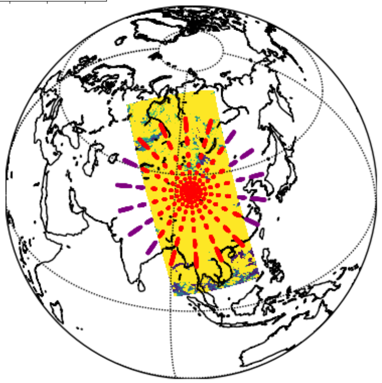


- Libera's split-SW ADM approach includes 3 generations, each with two scene stratifications



- Use of the Libera camera to generate ADMs requires carefully selecting pixels, appropriate spatial weighting, and spectral conversion

…"the challenges"



- Simulation experiments show that the Libera camera can provide dense angular sampling for rapid ADM development

…"the opportunities"

Priorities for the near-future

- OSSE ADMs
  - *Angular* calculations with MODTRAN 6 on ~100 representative FV3 atmospheric profiles [Dan Feldman]
  - Once satisfied, extend to much larger set of profiles

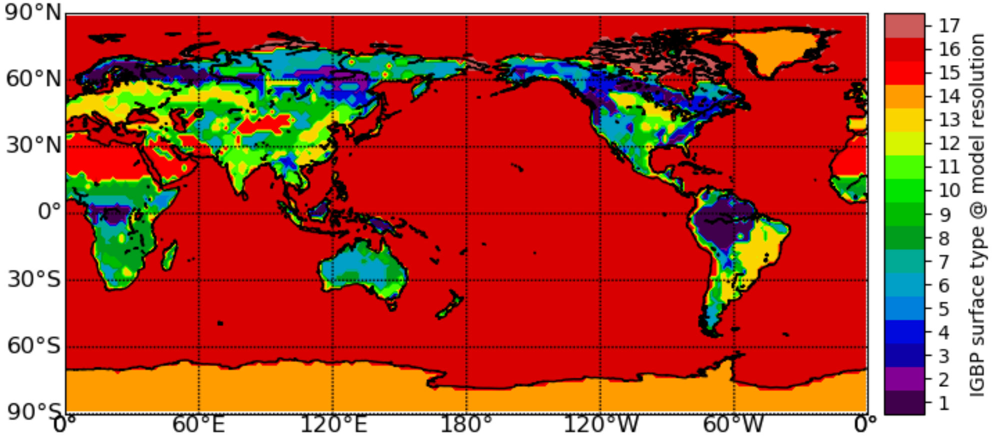
- Camera ADMs
  - Refinement of pixel masks consistent with camera capabilities [Sebastian Schmidt/Jake Gristey]
  - Single-wavelength to VIS angular relationship - statistical or translation from cross-track? [Josh Mauss]
  - Uncertainty propagation

- RAPS ADMs
  - RAPS rotation rate dependence on angular sampling [Matt van den Heever]
  - Implementation of ADMs with CERES data, possibly with refinement of ERBE and CERES scene types

ERBE scene type from OSSEs

extra

Surface type (IGBP)



Cloud fraction (CSIRO)

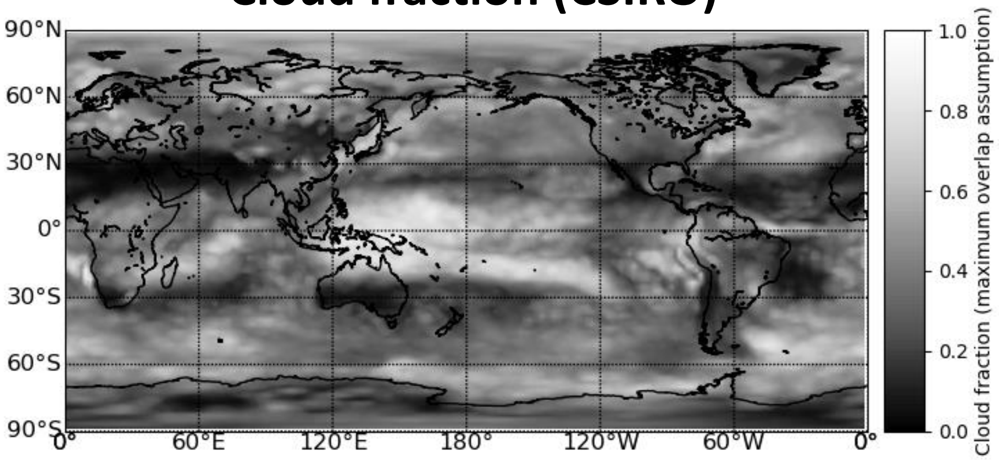


Table 1. Scene Types for Angular Models

Scene	Cloud coverage, percent
Clear over ocean	0 to 5
Clear over land	
Clear over snow	
Clear over desert	
Clear over land-ocean mix	
Partly cloudy over ocean	5 to 50
Partly cloudy over land or desert	5 to 50
Partly cloudy over land-ocean mix	5 to 50
Mostly cloudy over ocean	50 to 95
Mostly cloudy over land or desert	50 to 95
Mostly cloudy over land-ocean mix	50 to 95
Overcast	95 to 100

- All surfaces considered “land” except ocean, snow, desert, land-ocean mix

- Only select surface type with >90% in model grid
  - For land-ocean mix only select 30-70% ocean

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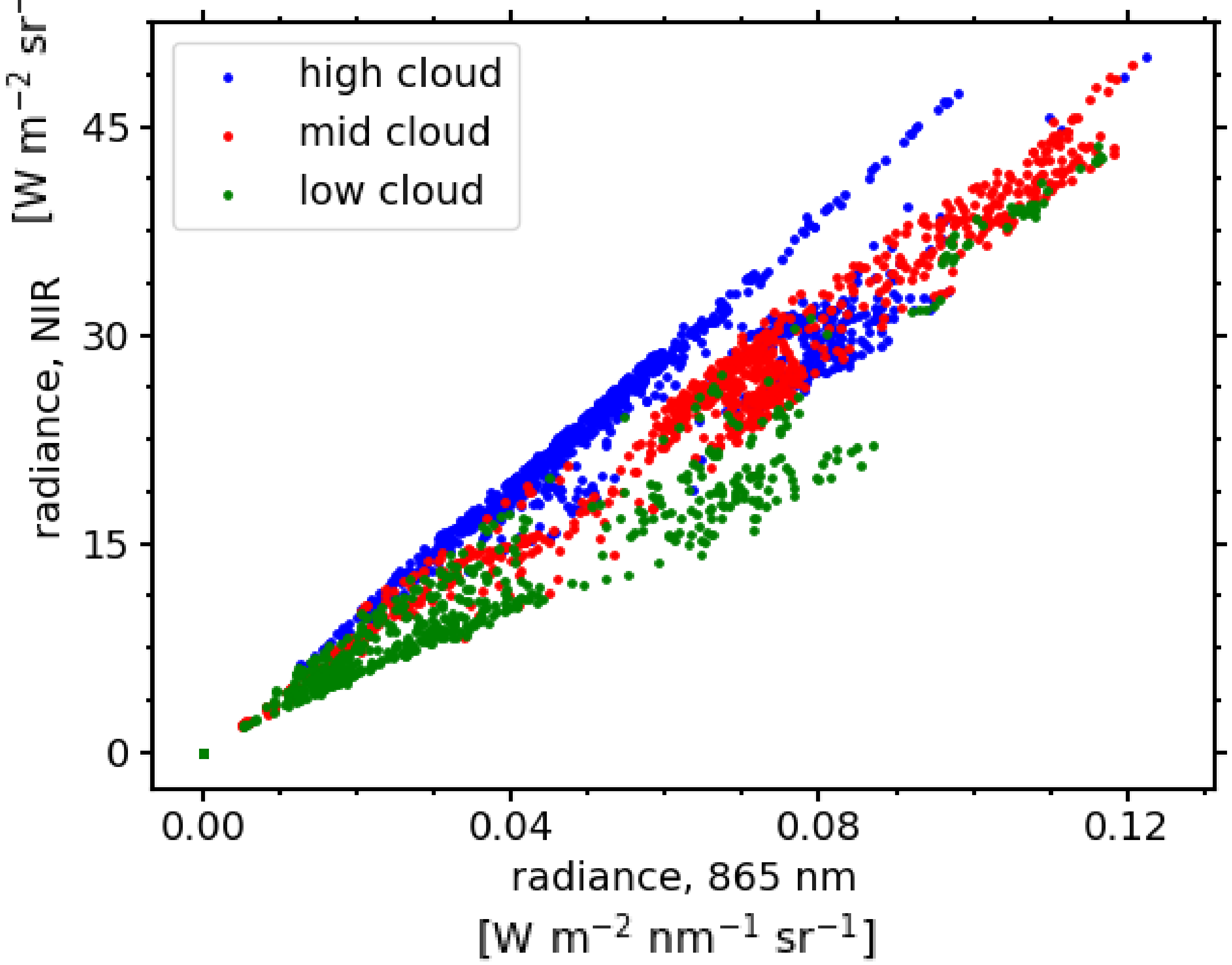
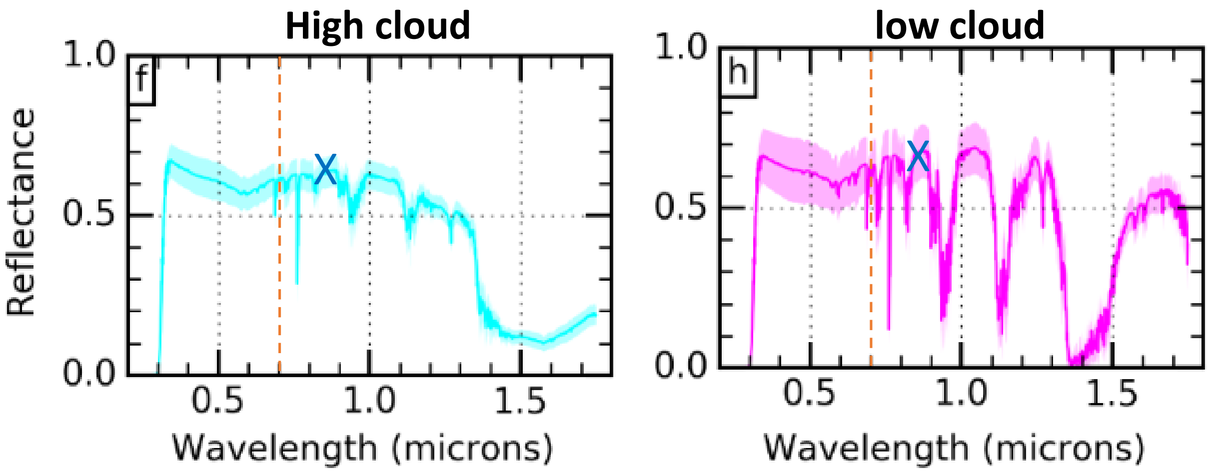
Cloud height separates “arms” very well

extra

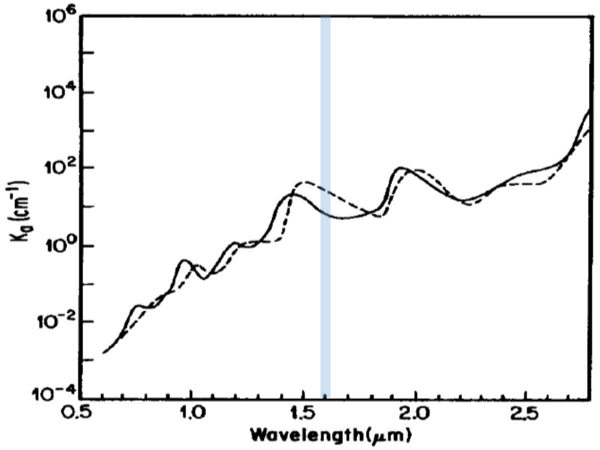
Note: nadir only



Gristey et al., J. Clim., 2019



Pilewskie and Twomey, JAS, 1987



Two reasons:

1. *Above cloud water vapor*
2. *Cloud phase*

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Transitioning between generations of ADMs

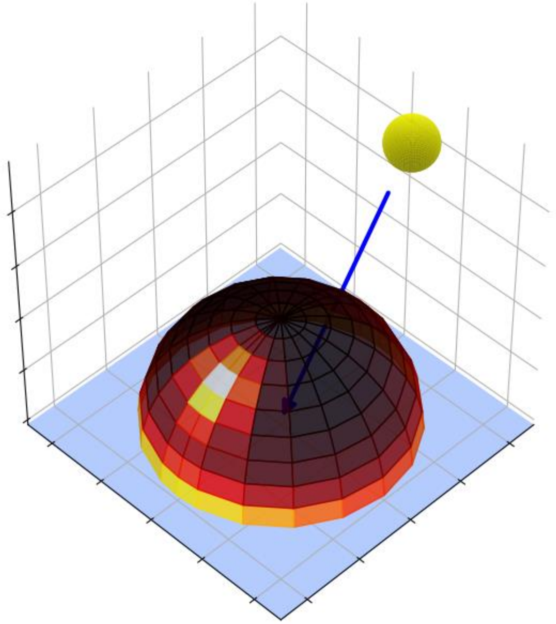
extra

- OSSEs (1st step) will provide angularly-complete ADMs for all scene types
- Camera ADM samples (2nd step) will not sample all angular bins for all scene types
  - >50% of angular space for all/most scene types?
  - OSSE will "fill in", but need to adjust to camera radiometric scale

$$\bar{I}_{ijk} = \bar{I}_{ijk}^{OSSE}\left[\sum_{m=1}^{M}\sum_{n=1}^{N}\left(\frac{\bar{I}_{imn}^{CAM}}{\bar{I}_{imn}^{OSSE}}\right)\right]/MN$$

- RAPS samples (3rd step) will also not provide complete sampling, and will take even longer to meet threshold
  - >50% of angular space for all/most scene types?
  - OSSE+camera will "fill in", but need to readjust to radiometer radiometric scale

$$\bar{I}_{ijk} = \bar{I}_{ijk}^{CAM}\left[\sum_{m=1}^{M}\sum_{n=1}^{N}\left(\frac{\bar{I}_{imn}^{RAPS}}{\bar{I}_{imn}^{CAM}}\right)\right]/MN$$



<u>Key</u>

$\bar{I}$: mean radiance

i, j, k : SZA, VZA, RAA bin indices

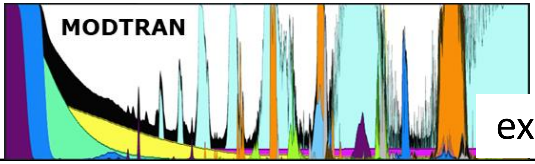
M, N : total number of VZA and RAA bins with combined samples

1. OSSE “prior” ADMs [pre-launch]

extra

- Simple concept: generate angularly-complete ADMs for all scene types via radiative transfer

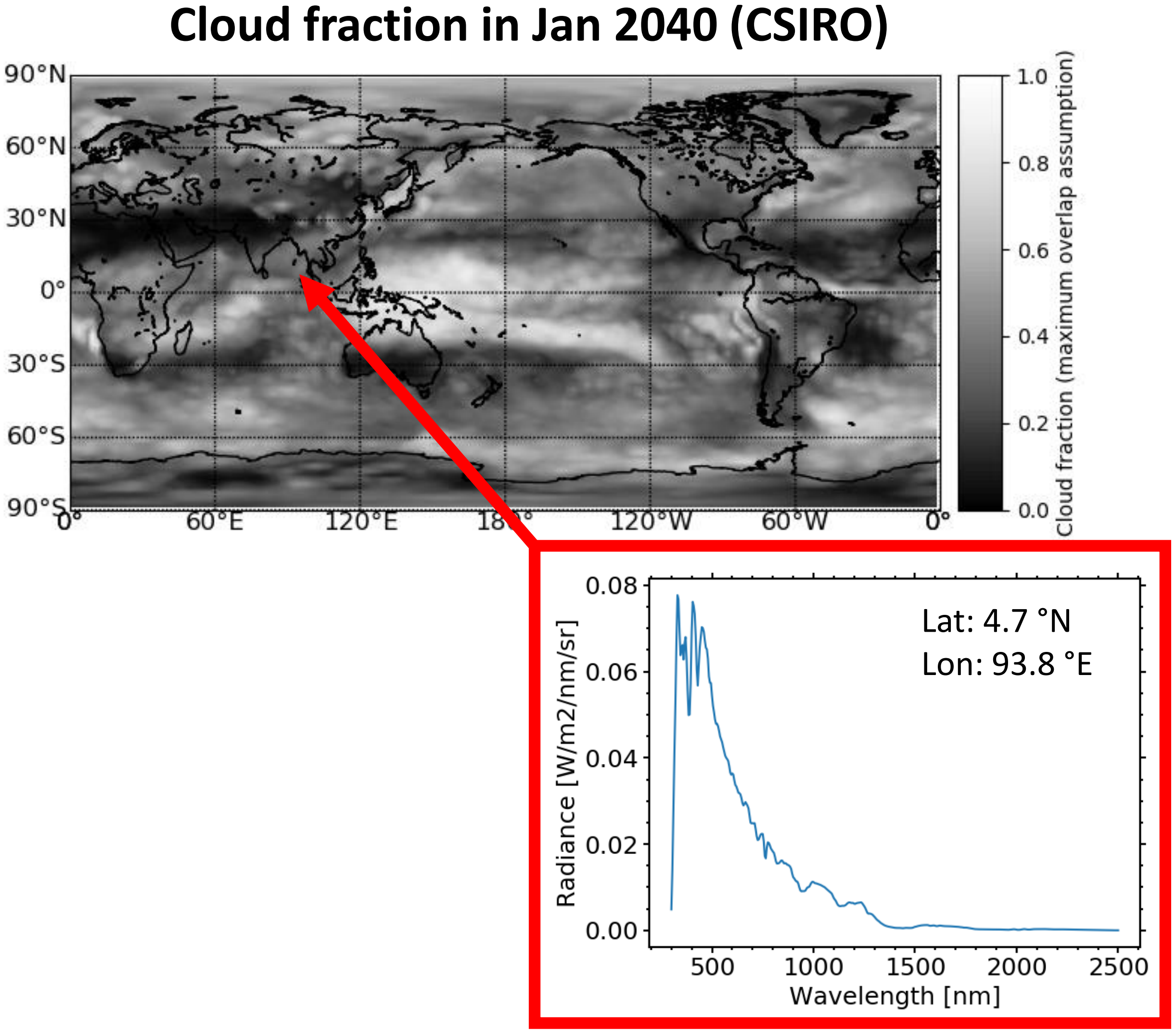
1. OSSE “prior” ADMs [pre-launch]



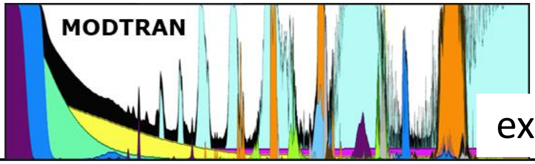
extra

- Simple concept: generate angularly-complete ADMs for all scene types via radiative transfer

- Start with existing Observing System Simulation Experiment (OSSE) framework
  Feldman at al. , JGR (2011a&b); J. Clim. (2013); Geosci. Mod. Dev. (2015)
  - ➢ Use high resolution profiles as input rather than climate model (e.g. GSRMs such as FV3) *Stevens et al., (2019)*
  - ➢ Output at a range of solar-viewing geometries



1. OSSE "prior" ADMs [pre-launch]



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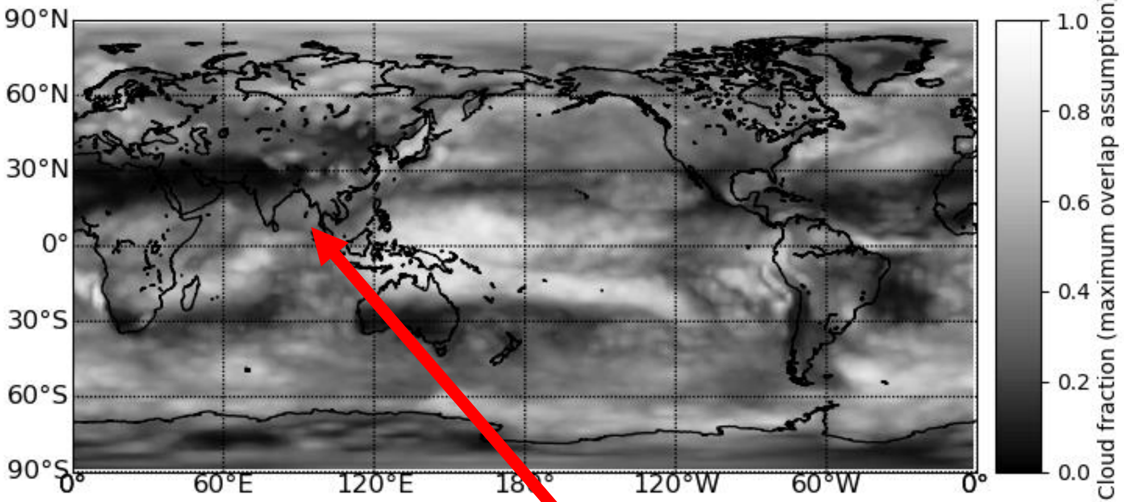
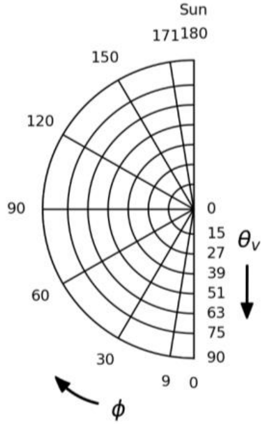
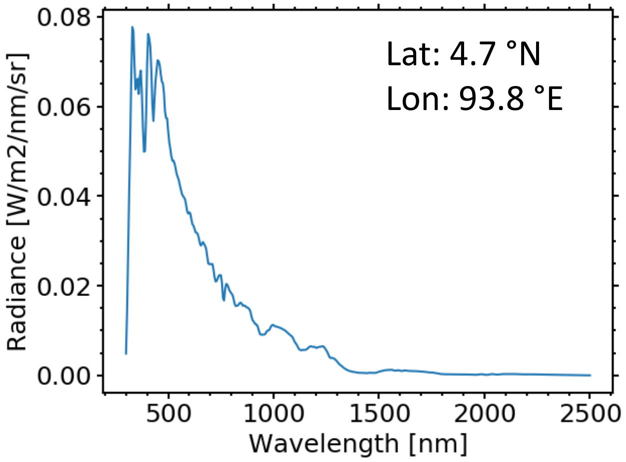
Cloud fraction in Jan 2040 (CSIRO)



Imager independent: Group simulated radiances by **ERBE-like** scene types and angular bins

Scene ID Number	Cloud Fraction	Surface Type
1	Cloud-free (0–5%)	Ocean
2	Cloud-free (0–5%)	Land
3	Cloud-free (0–5%)	Snow
4	Cloud-free (0–5%)	Desert
5	Cloud-free (0–5%)	Land-ocean mix
6	Partly cloudy (5–50%)	Ocean
7	Partly cloudy (5–50%)	Land or desert
8	Partly cloudy (5–50%)	Land-ocean mix
9	Mostly cloudy (50–95%)	Ocean
10	Mostly cloudy (50–95%)	Land or desert
11	Mostly cloudy (50–95%)	Land-ocean mix
12	Overcast	All





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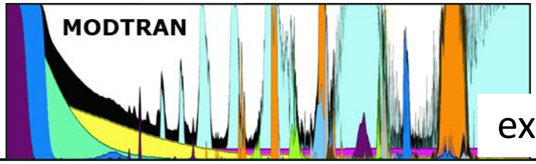

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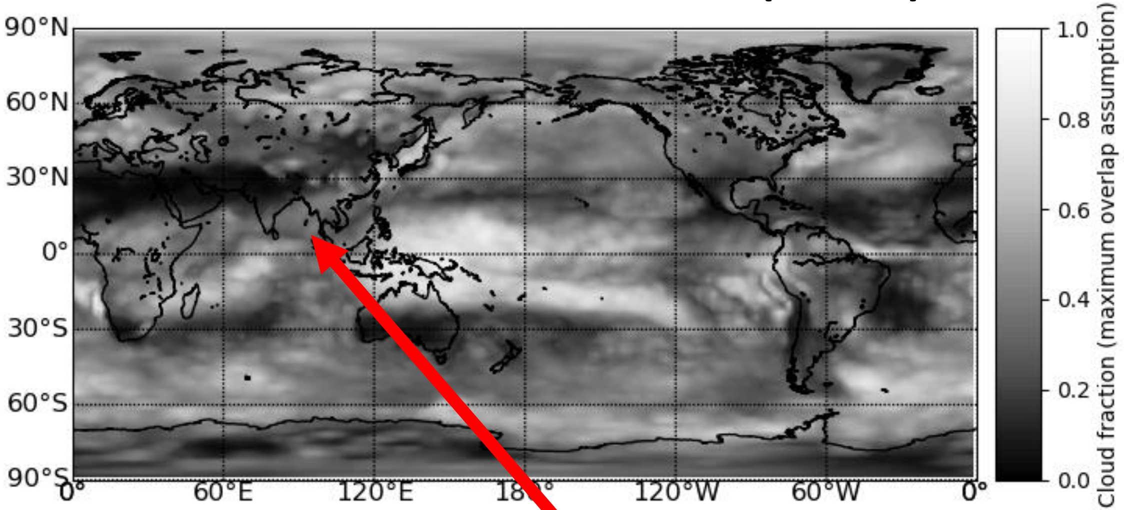
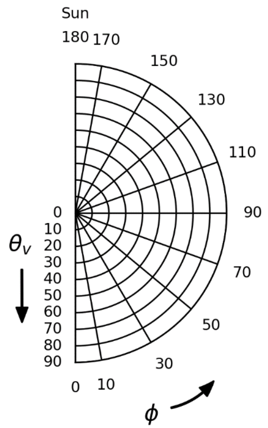
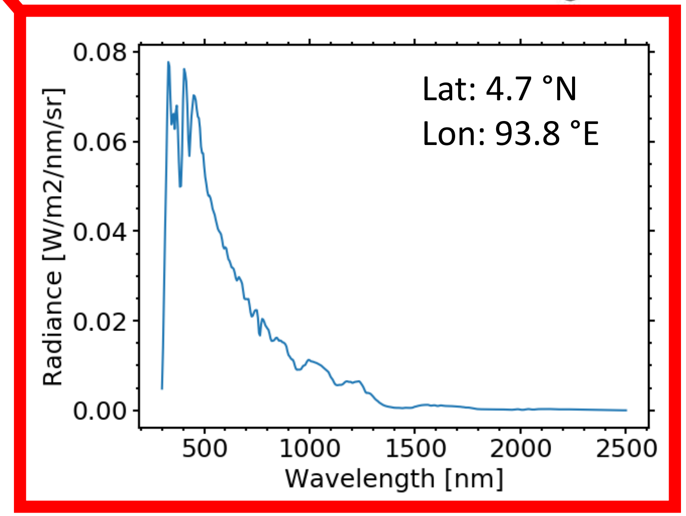


Best available: Group simulated radiances by **CERES-like** scene types and angular bins

Surface Type	Cloud Thermodynamic Phase	Cloud Fraction (%)	Cloud Optical Depth
Ocean (336)	Liquid, ice	0.1–10, 10–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–90, 90–95, 95–99.9, 99.9–100	0.01–1.0, 1.0–2.5, 2.5–5.0, 5.0–7.5, 7.5–10, 10–12.5, 12.5–15, 15–17.5, 17.5–20, 20–25, 25–30, 30–40, 40–50, >50
Moderate–high tree/shrub coverage (60), low–moderate tree/shrub coverage (60), dark desert (60), bright desert (60)	Liquid, ice	0.1–25, 25–50, 50–75, 75–99.9, 99.9–100	0.01–2.5, 2.5–6, 6–10, 10–18, 18–40, >40



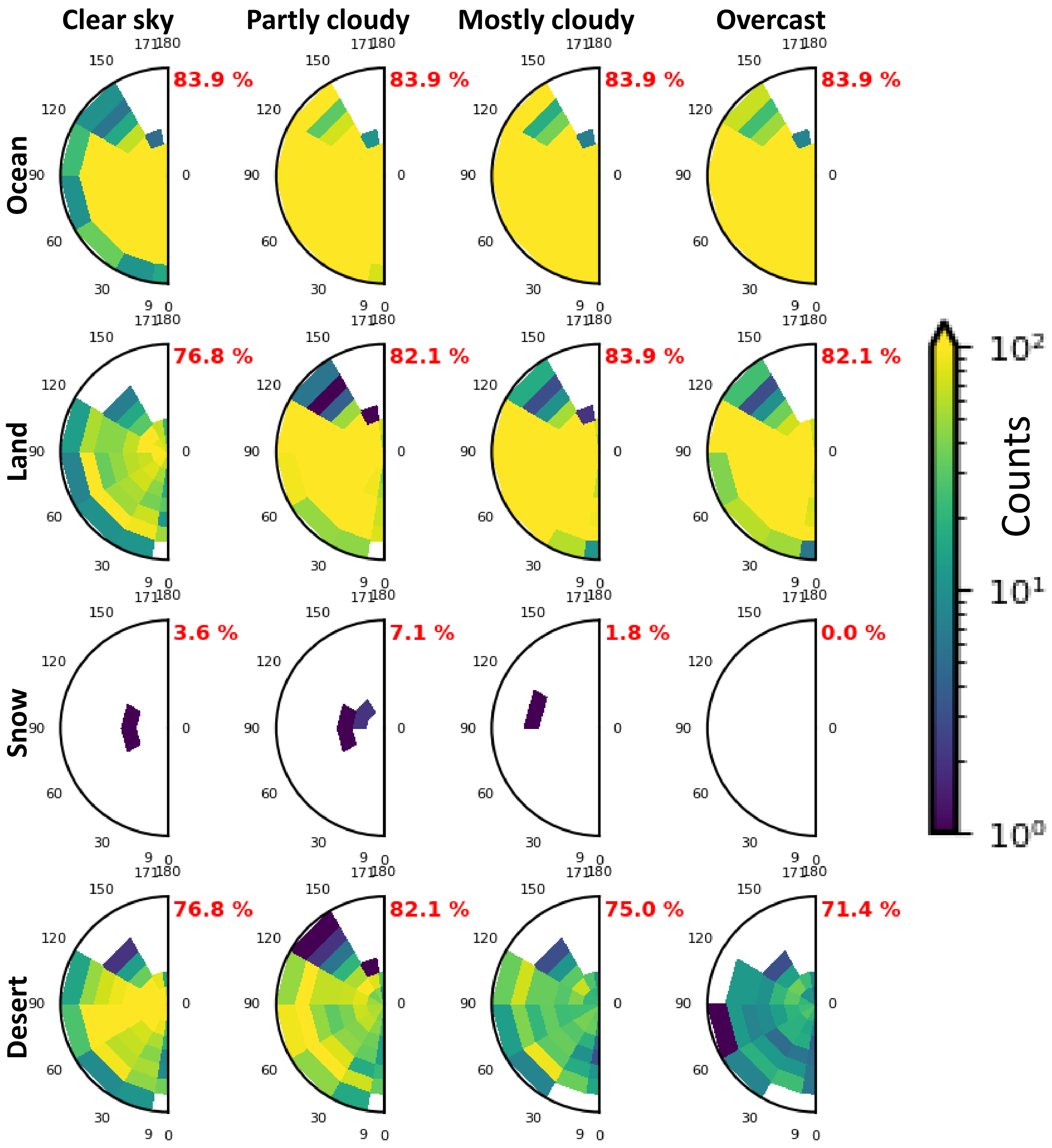


2021-01-01

- SZA: 0.00 – 25.84°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

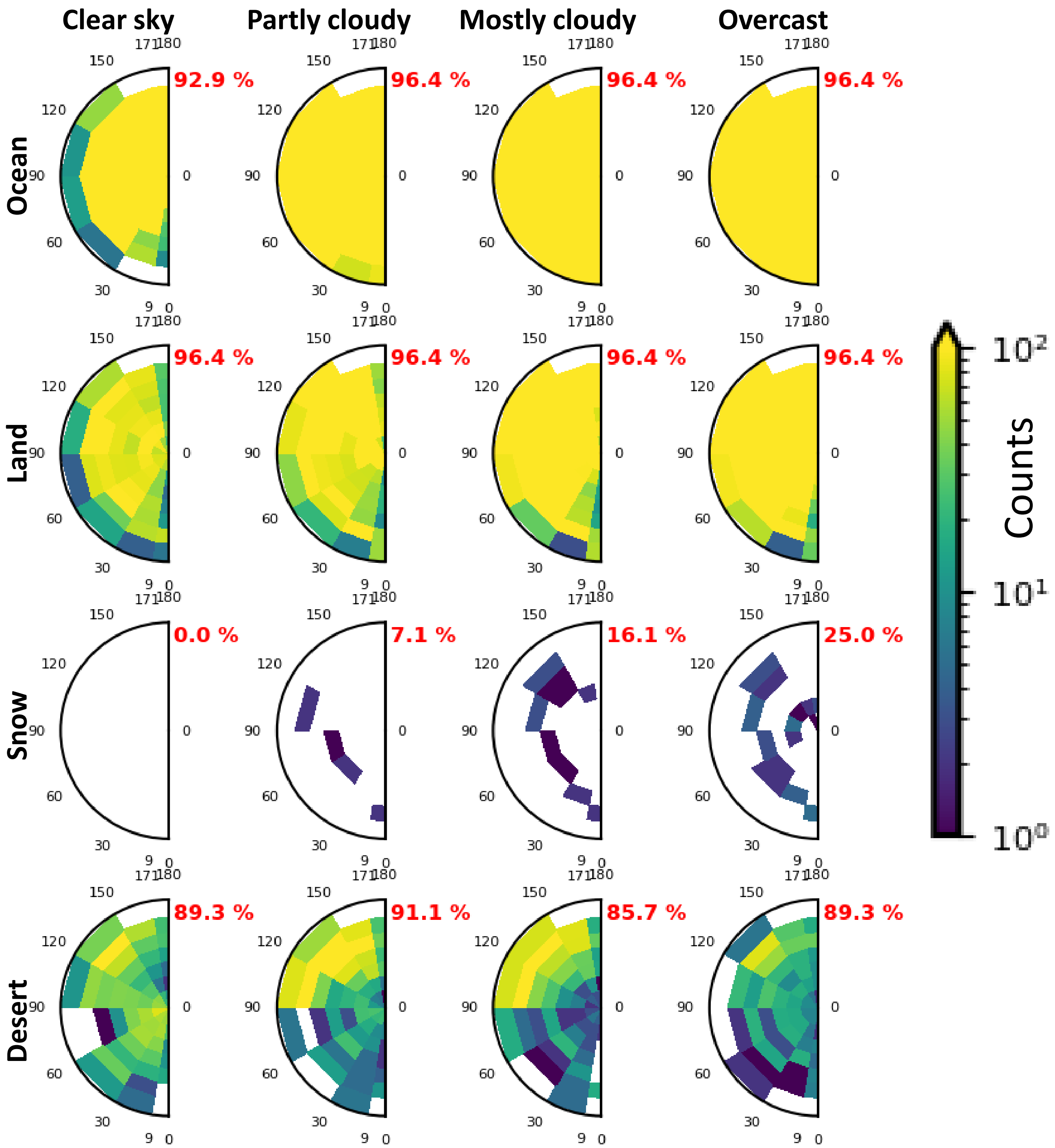


2021-01-01

- SZA: 25.84 – 36.87°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

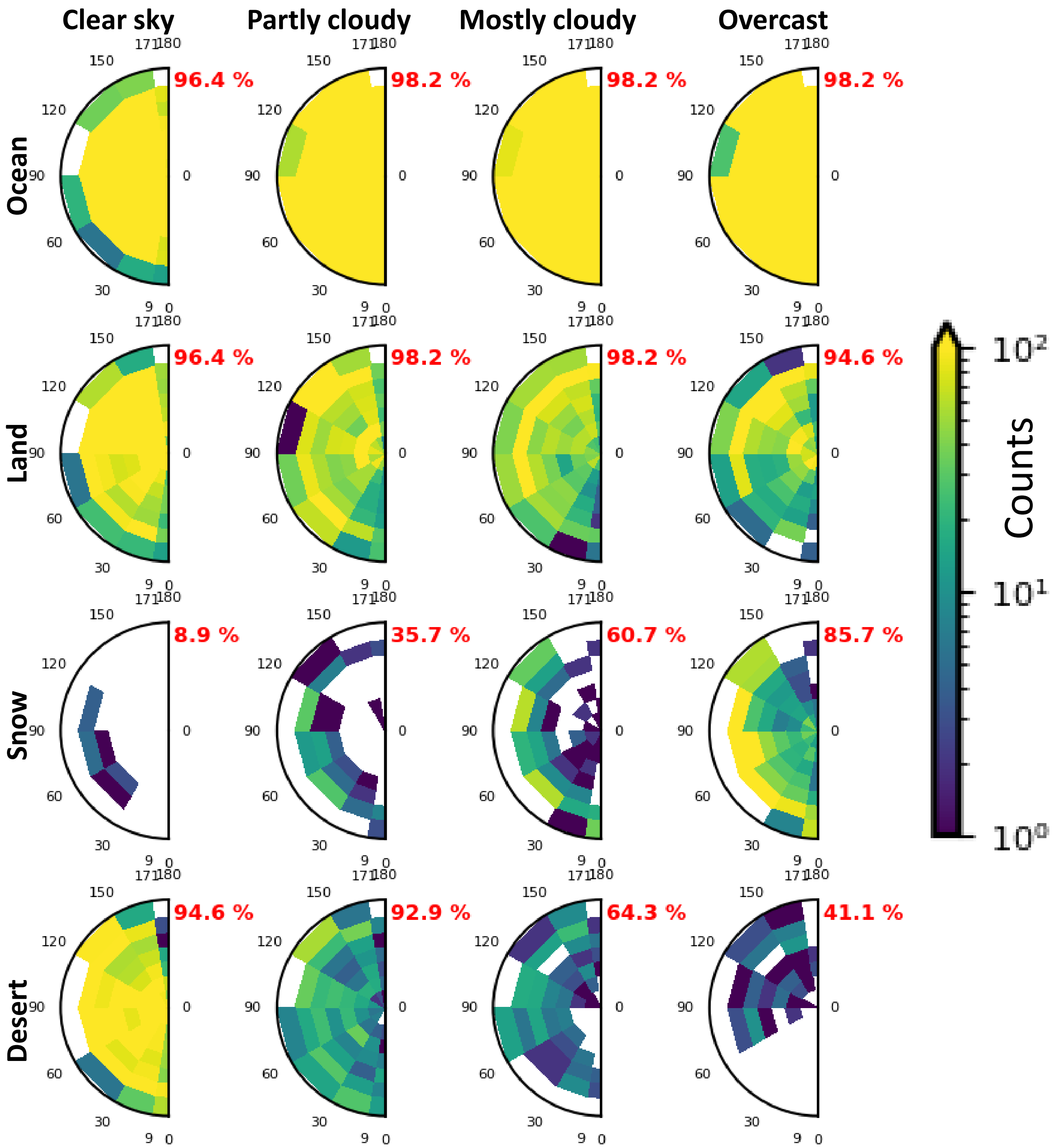


2021-01-01

- SZA: 36.87 – 45.57°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

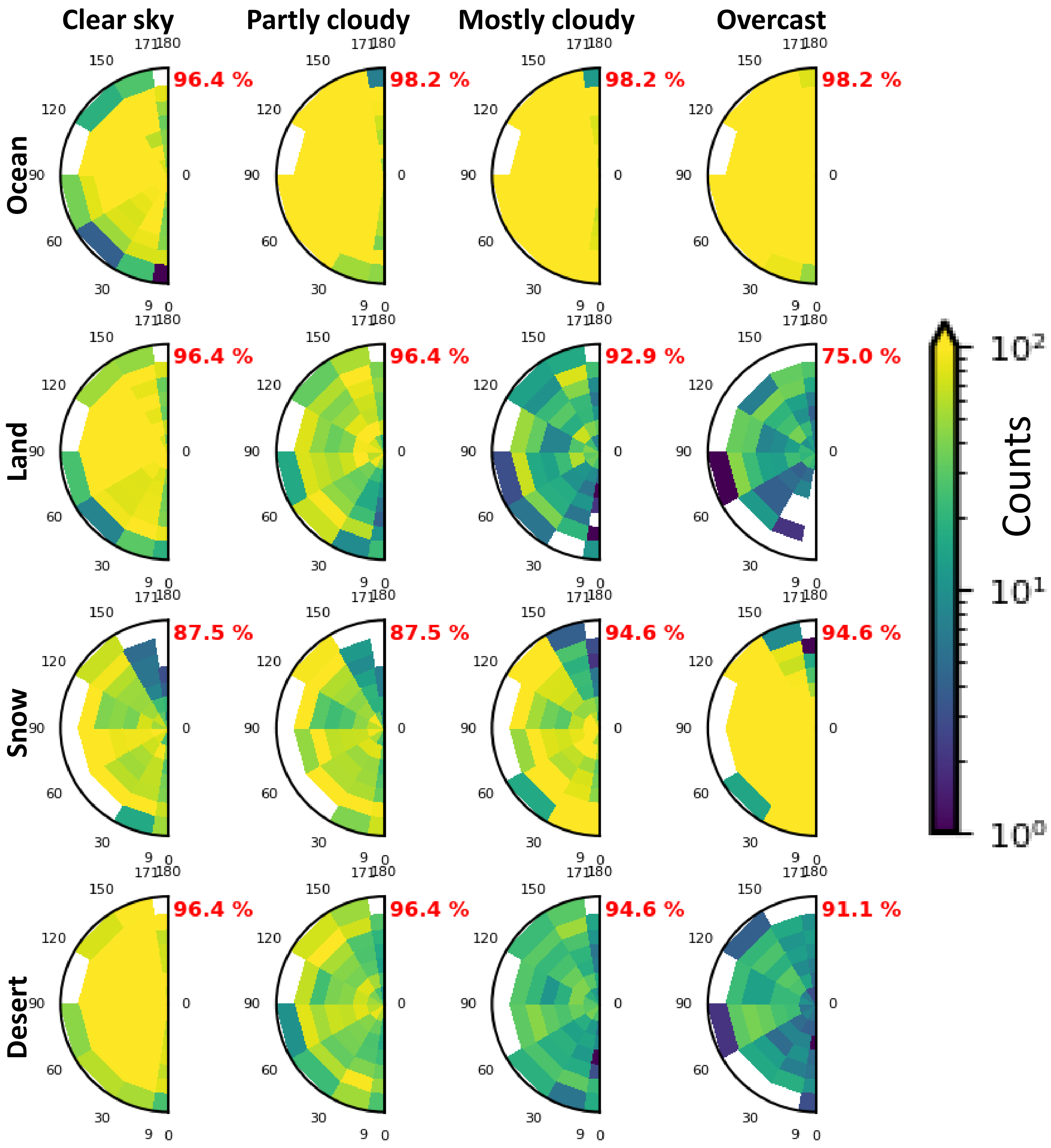


2021-01-01

- SZA: 45.57 – 53.13°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

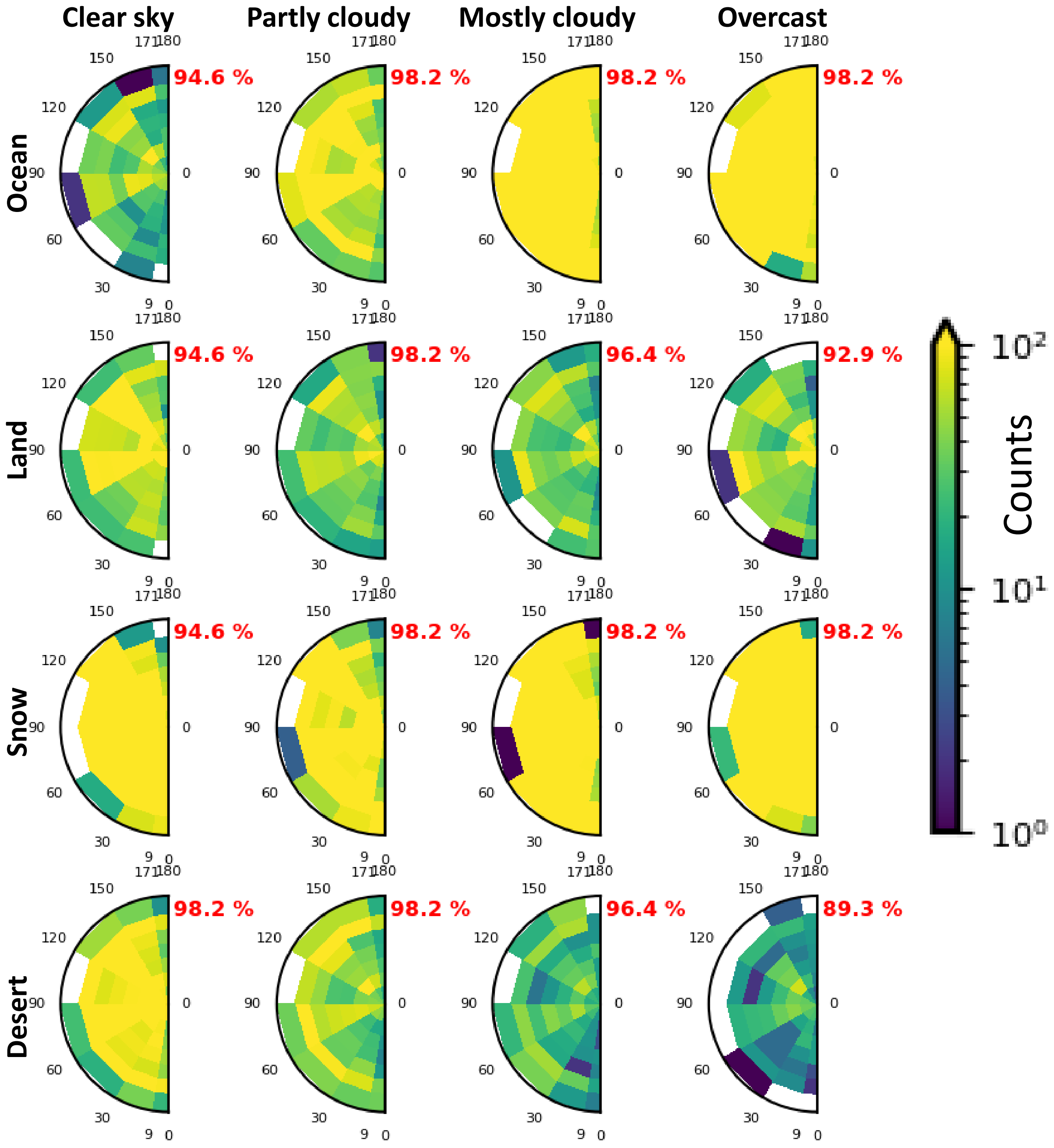


2021-01-01

- SZA: 53.13 – 60.00°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

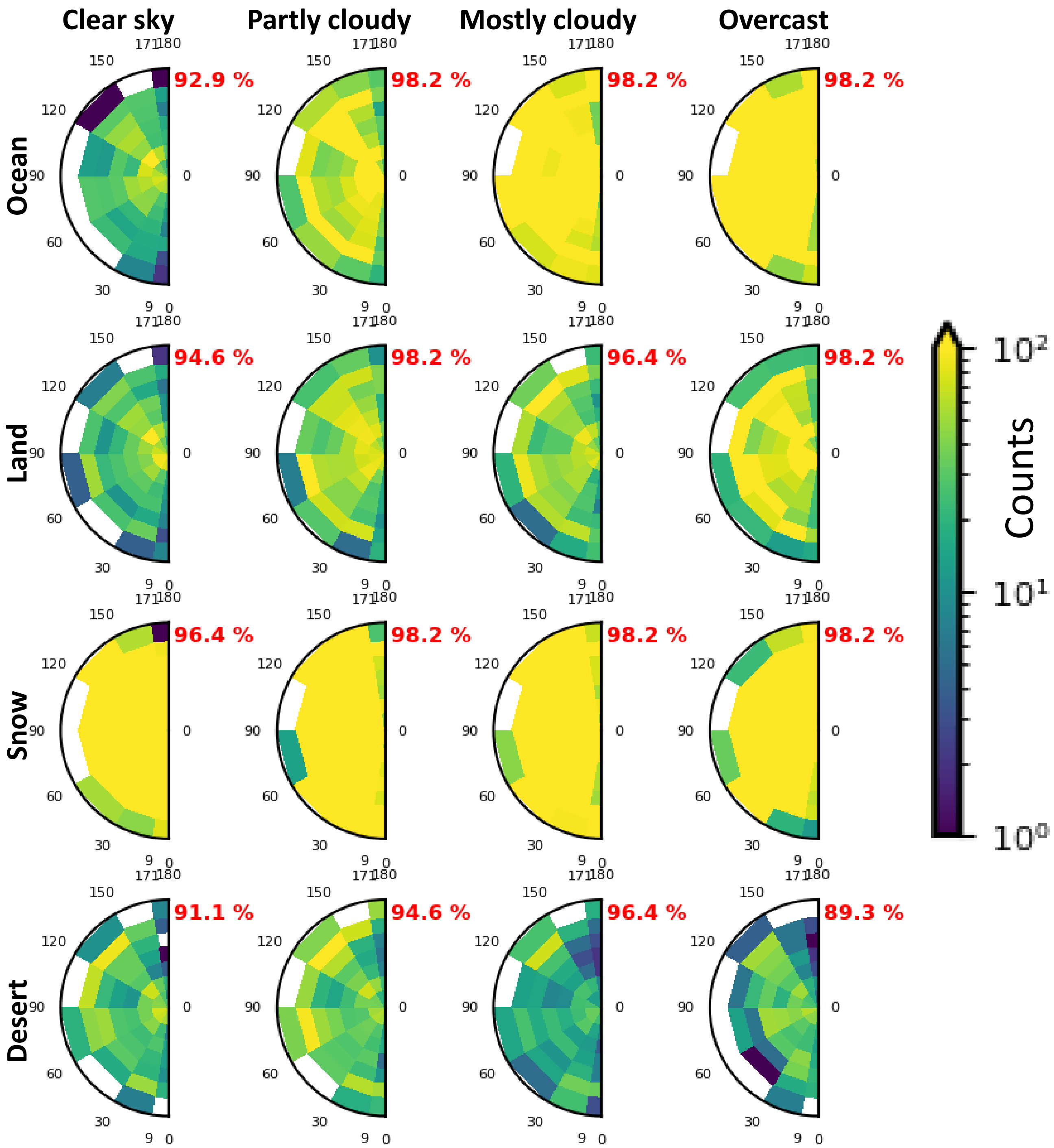


2021-01-01

- SZA: 60.00 – 66.42°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

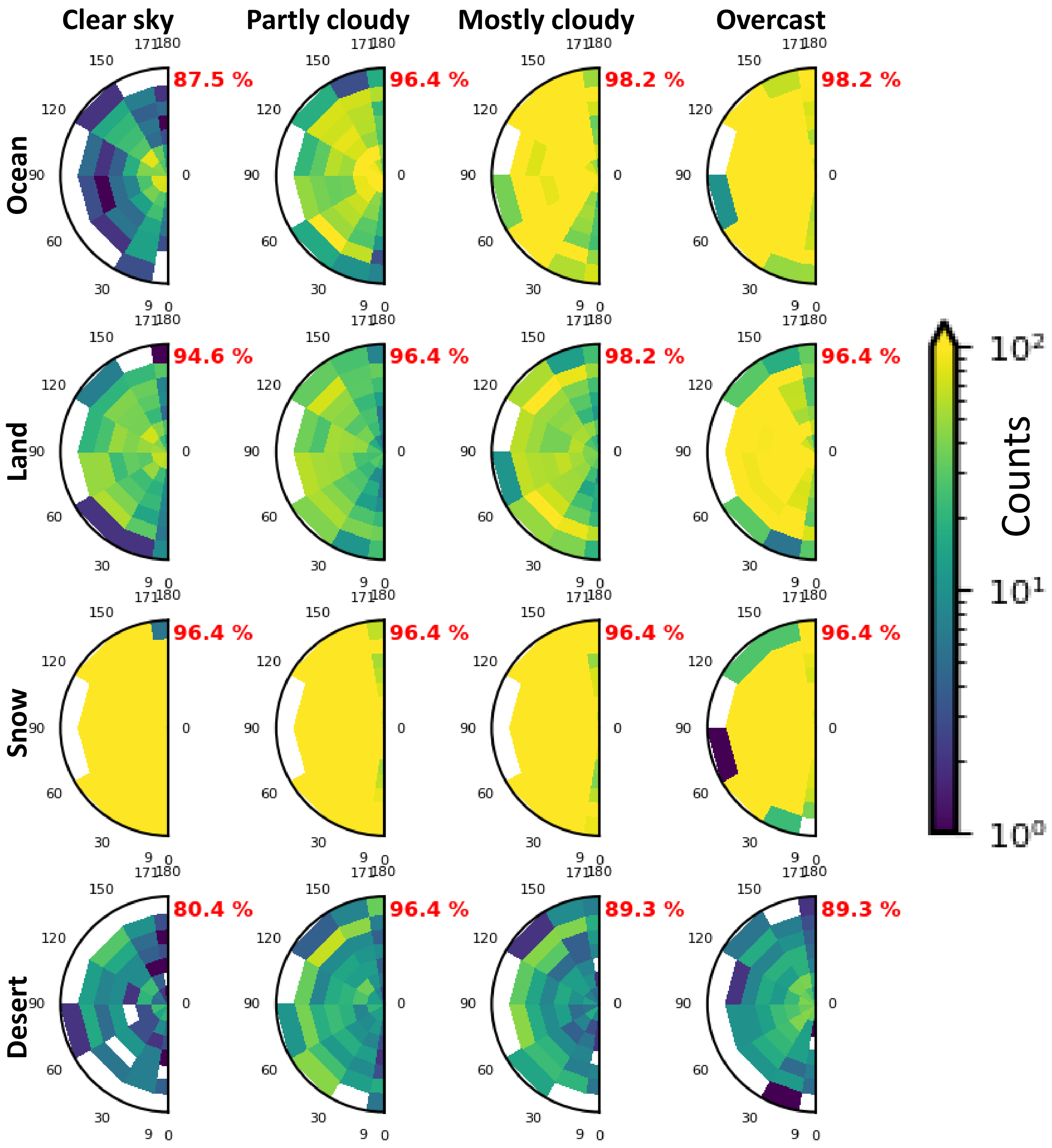


2021-01-01

- SZA: 66.42 – 72.54°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling

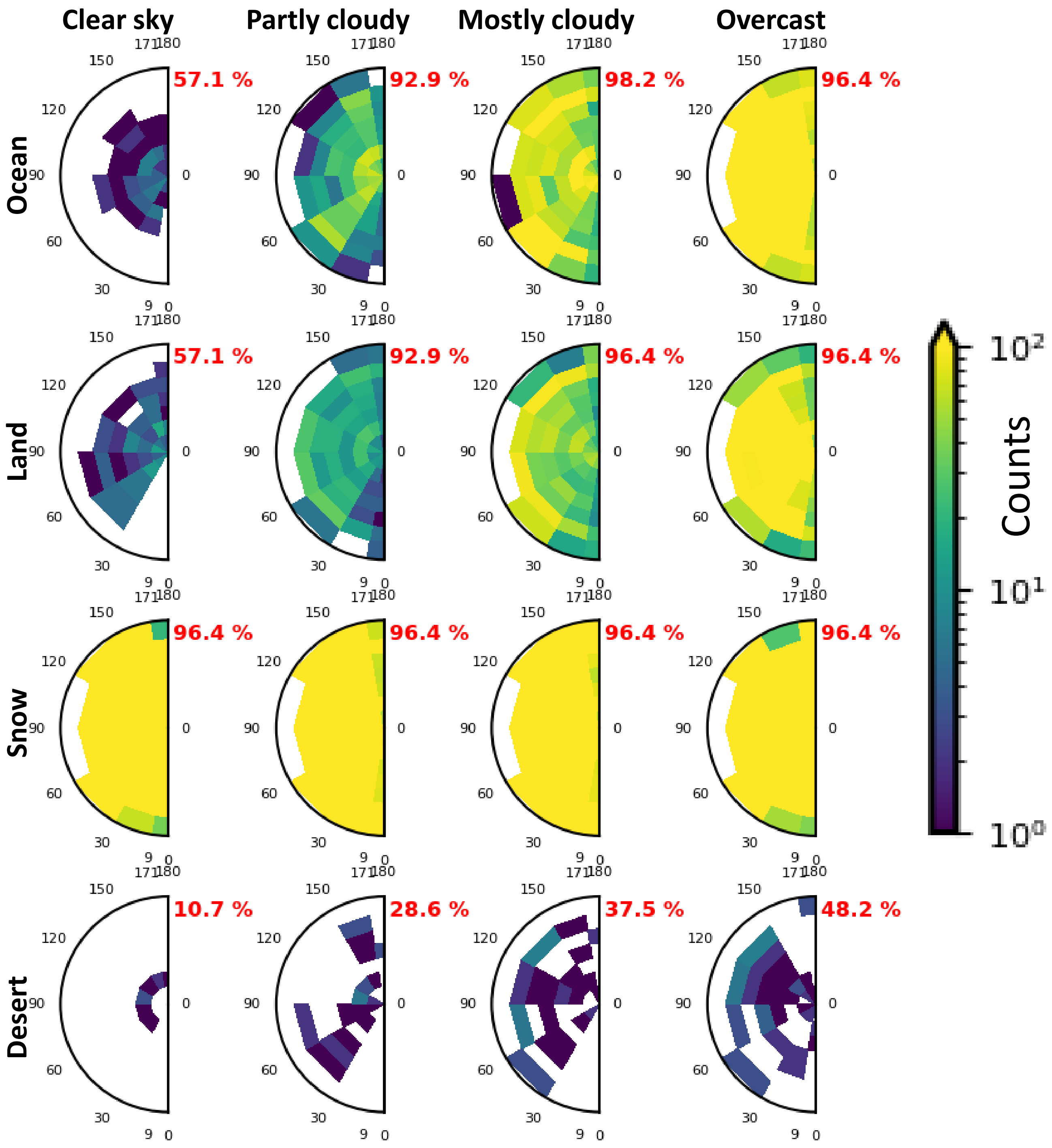


2021-01-01

- SZA: 72.54 – 78.46°

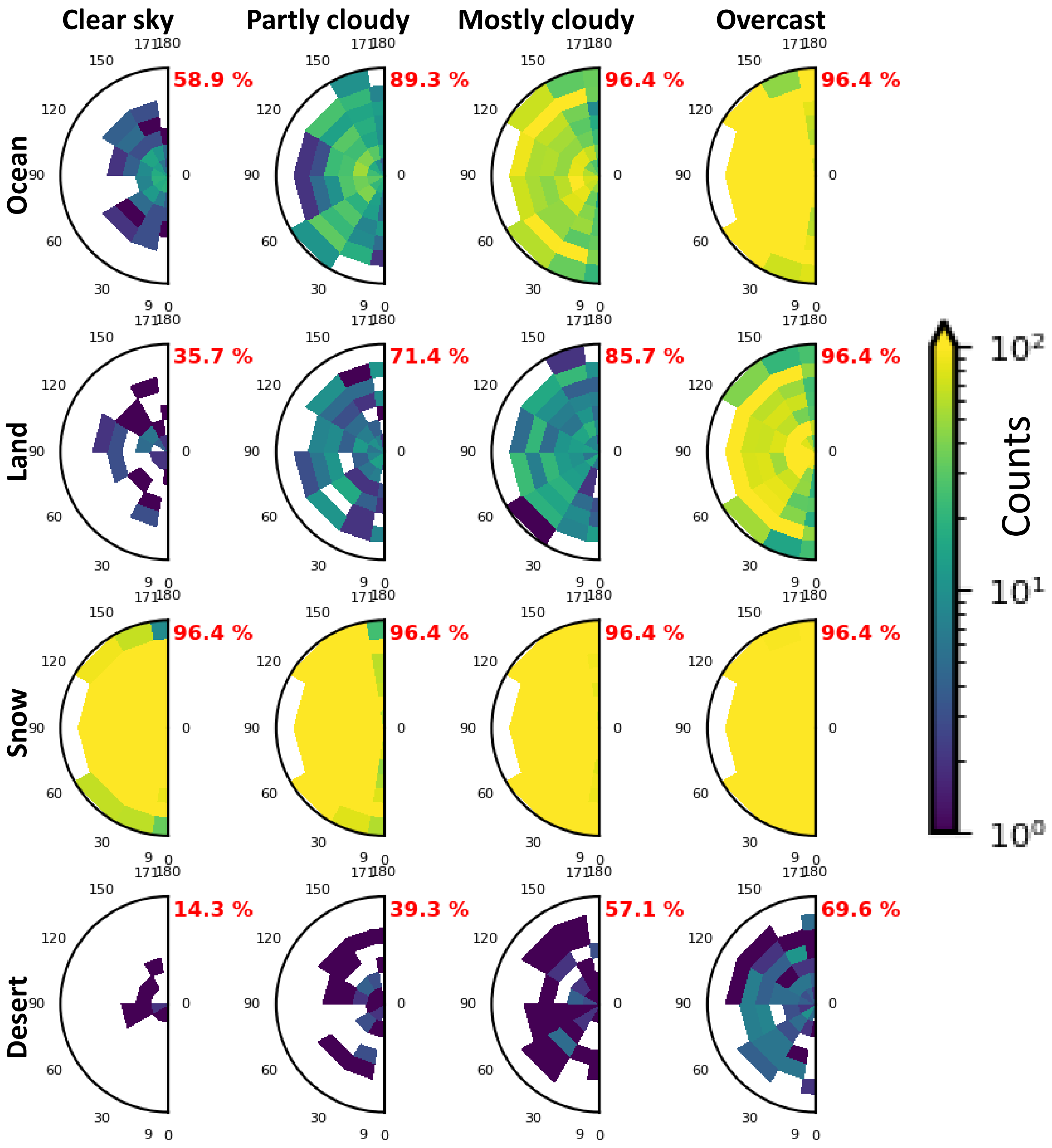
- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling



2021-01-01

- SZA: 78.46 – 84.26°
- systematic sampling (100% of bins per exposure)
- 23 hrs of sampling



2021-01-01

- SZA: 84.26 – 90.00°

- systematic sampling (100% of bins per exposure)

- 23 hrs of sampling